National Aeronautics and Space Administration

Proposed Framework for developing a Comprehensive ARMD Full UAS Integration Strategy

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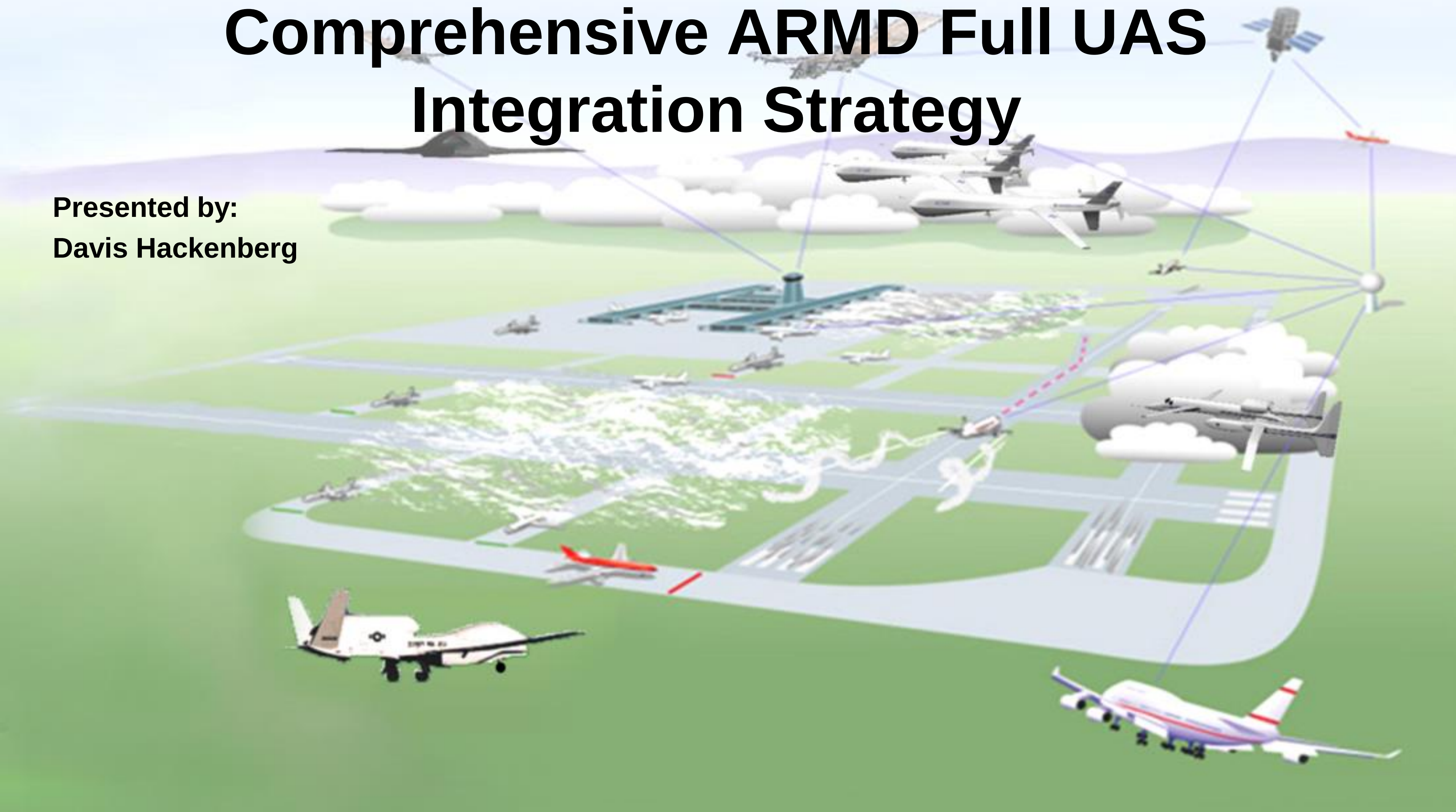


Purpose / Scope / Outcome

- **Purpose**: Provide a framework for a strategic architecture to develop and manage a research portfolio focused on full UAS integration
- **Scope**: Focus on what is needed to enable full integration of unmanned aircraft for civil / commercial operations within the U.S. NAS by ~2025.
  - Leverage work done under previous years UAS Full Integration Study
  - Engage Community to elicit their input
  - Provide a framework and technical approach for the analysis
  - Develop a decision support tool than can assist ARMD with determining their role
- **Desired Outcome**: A plan for a "Comprehensive ARMD Full UAS Integration Strategy"

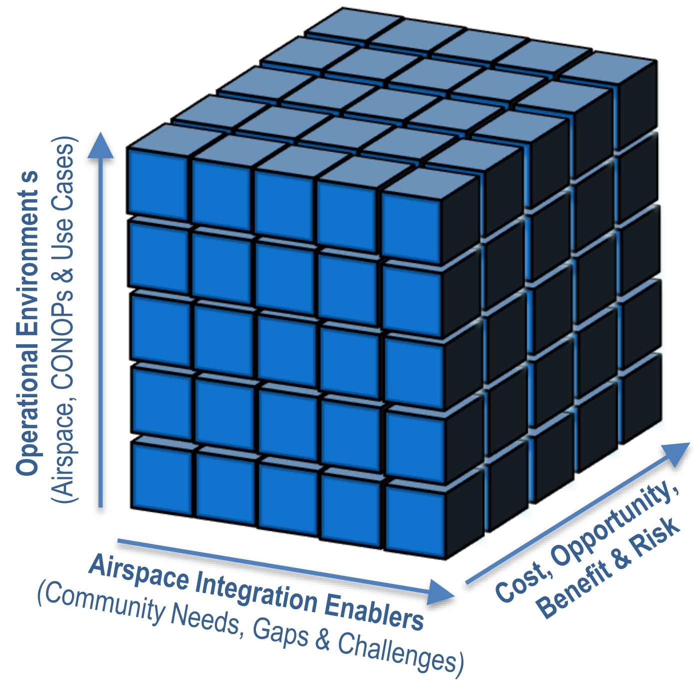
Enabling Full Integration of UAS for civil / commercial operations within the NAS by 2025

Like manned aircraft, UAS will be able to routinely operate through all phases of flight in the NAS, based on vehicle and infrastructure performance capabilities

Attributes of a Full UAS Integration Framework

- UAS Full Integration is a multi-dimensional challenge facing the UAS Community

- An Analytical Framework must consider all aspects, to include:
  - The ***Airspace Integration Enablers*** (i.e. Community Needs, Gaps & Challenges)
  - The ***Operational Environment*** the UAS intends to operate within (i.e. Airspace Type, UAS CONOPs, Use Cases)
  - The associated ***Cost, Opportunity, Benefit and Risk*** for each element within the framework
    - Gap size/complexity will drive *cost/schedule* and encourage partnerships
    - *Cost to close the gap* vs *cost to implement* vs *potential return on investment* are all important considerations
    - Each gap has unique *opportunities* and *risks*
    - Closure of gaps will have different degrees of community *benefit*



- Other considerations:
  - Ongoing work within the Community
  - Organizational strengths/weaknesses
  - Leadership vision
  - Political drivers
  - Social pressures

The Analytical Framework must be capable of addressing the multi-dimensional challenges associated with UAS Full Integration

UAS Full Integration Framework Study

Technical Approach

Steps for developing a Framework leading to a "Comprehensive ARMD Full UAS Integration Strategy"

1) Define & Scope Community Needs

- **1a** Identify Full UAS Integration gaps/challenges and group into AI Enabler Categories
- **1b** Determine appropriate Operational Environments to help scope problem
- **1c** Define meaningful Evaluation Criteria & Weighting Values

OUTPUT

Full UAS Integration Community Needs, Operational Environments & Evaluation Criteria

2) Cost, Opportunity, Benefit, Risk Assessment

- **2a** Derive relative costs needed to close the gap & implement the solution
- **2b** Evaluate Cost, Opportunity, Benefit, Risk for each AI Enabler & Operational Environment

OUTPUT

Relative Cost Assessment & Prioritized set of Community Needs by Operating Environment

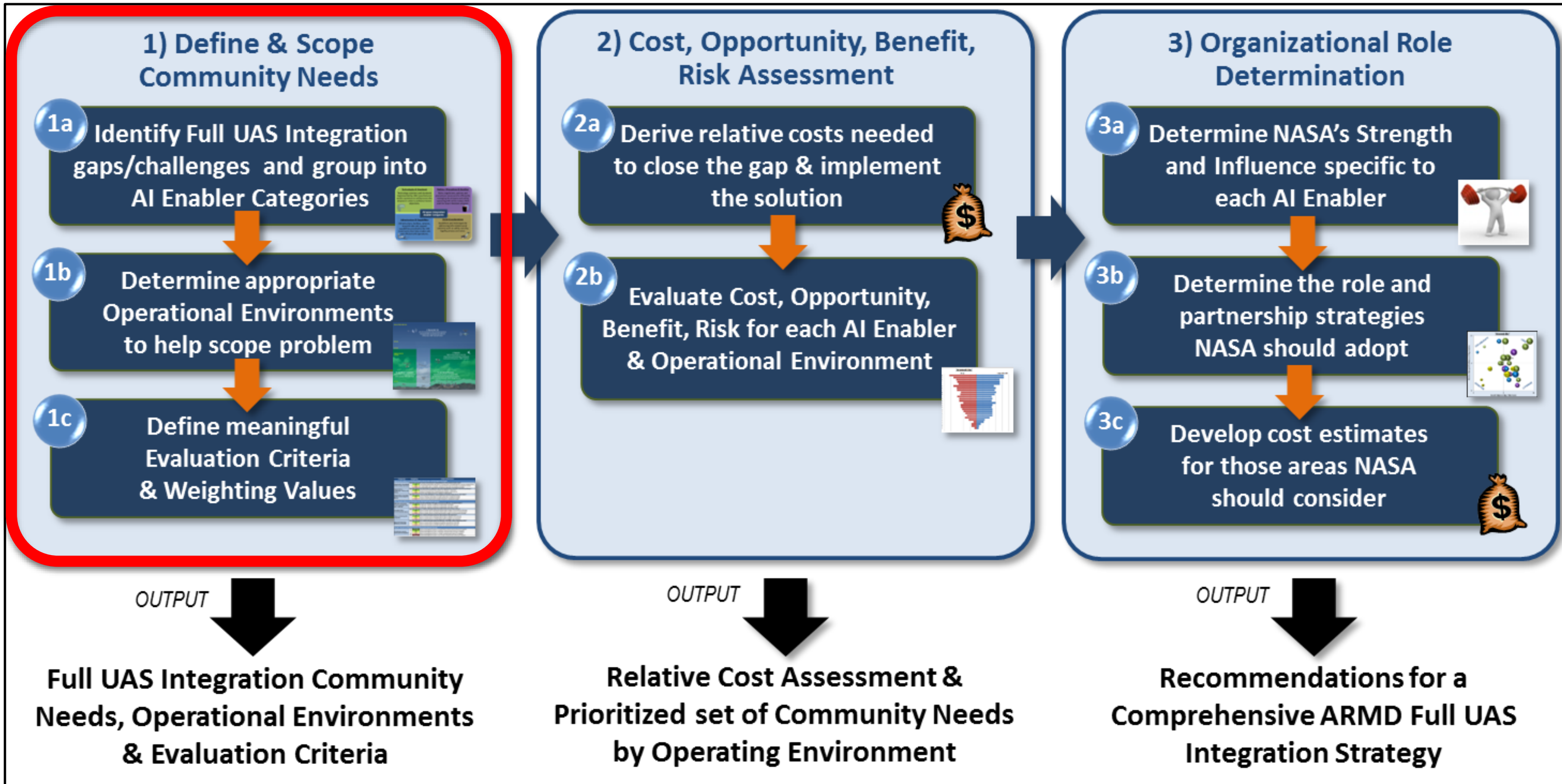
3) Organizational Role Determination

- **3a** Determine NASA's Strength and Influence specific to each AI Enabler
- **3b** Determine the role and partnership strategies NASA should adopt
- **3c** Develop cost estimates for those areas NASA should consider

OUTPUT

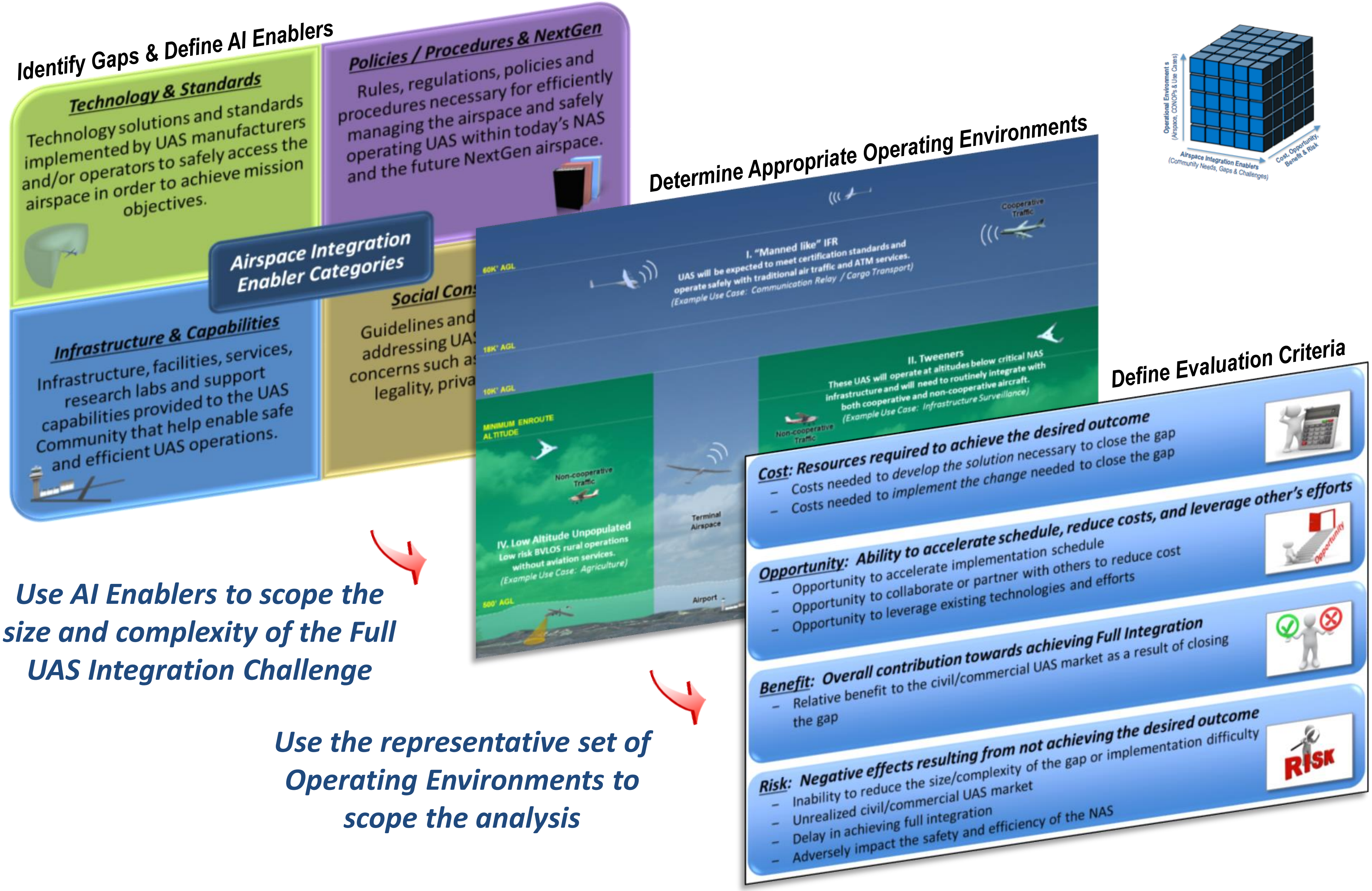
Recommendations for a Comprehensive ARMD Full UAS Integration Strategy

External Community Involvement | *NASA Internal Only*



STEP 1: DEFINE & SCOPE COMMUNITY NEEDS

Develop AI Enablers, Operating Environments & Evaluation Criteria

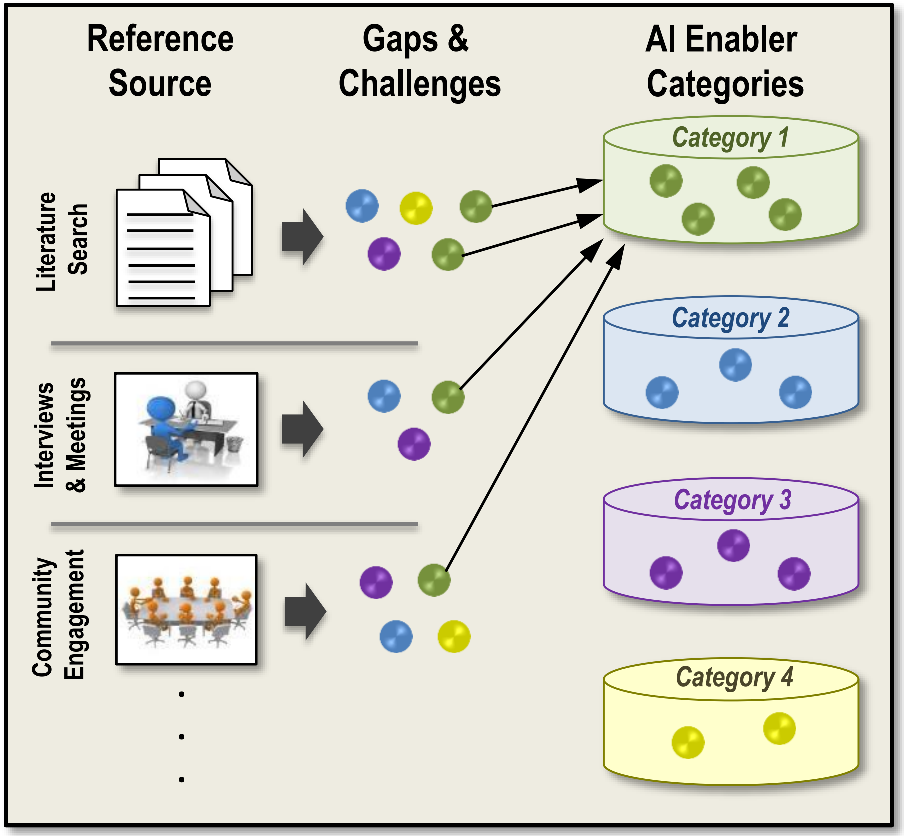


Use AI Enablers to scope the size and complexity of the Full UAS Integration Challenge

Use the representative set of Operating Environments to scope the analysis

Identify Community Needs/Gaps/Challenges

- Leverage previous UAS Full Integration Studies performed in 2014 & 2015
  - Assessed multiple documents from across the UAS community to identify full UAS integration gaps and challenges
- Consider new efforts & recent developments
  - NASA UTM
  - FAA Guidance (e.g. sUAS Rule)
  - Industry business cases
- Engage UAS community stakeholders
  - OGA's (e.g. FAA, DoD, DHS, NOAA)
  - Trade Associations (e.g. AUVSI, AIAA)
  - Industry (e.g. Amazon, Google)
  - Academia (e.g. COE, UND)
  - International (e.g. ICAO, NATO)
- Utilize community needs/gaps to determine the Airspace Integration Enablers
  - Input to Decision Support Tool
  - Basis for Analytical Framework



The Airspace Integration Enablers form the foundational content that the Full UAS Integration analysis is centered around.

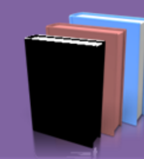
UAS Airspace Integration Enabler Categories

Technology & Standards

Technology solutions and standards implemented by UAS manufacturers and/or operators to safely access the airspace in order to achieve mission objectives.

Policies / Procedures & NextGen

Rules, regulations, policies and procedures necessary for efficiently managing the airspace and safely operating UAS within today's NAS and the future NextGen airspace.



Airspace Integration Enabler Categories

Infrastructure & Capabilities

Infrastructure, facilities, services, research labs and support capabilities provided to the UAS Community that help enable safe and efficient UAS operations.

Social Considerations

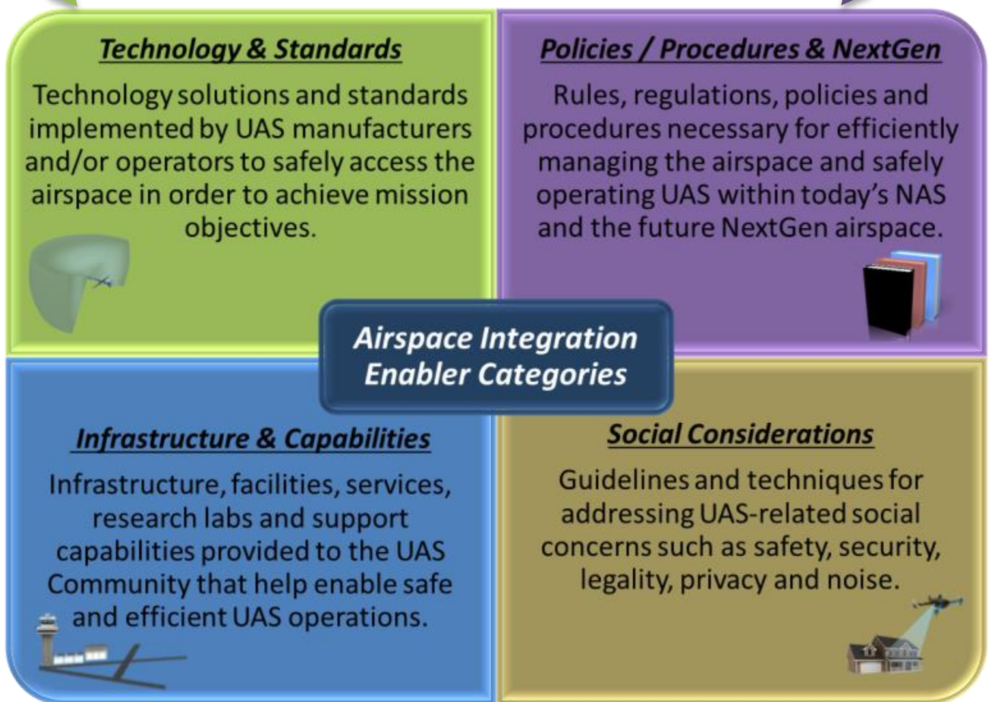
Guidelines and techniques for addressing UAS-related social concerns such as safety, security, legality, privacy and noise.

Airspace Integration Enabler Categories group the previously identified gaps and challenges into similar areas that must be addressed to achieve Full UAS Integration

UAS Airspace Integration Enabler Categories

T01 - Airport Surface Ops
T02 – Detect & Avoid (DAA)
T03 - Hazard Avoidance
T04 - C3 Technologies
T05 - GCS Technologies
T06 - Flight & Health Mngmt
T07 - Airworthiness
T08 - Navigation
T09 - Weather Avoidance
T10 - Power & Propulsion
T11 - Autonomous Architectures
T12 - Human Factors Guidelines

P01 - Airspace Mngmt Pol. / Proc.
P02 - Operating Rules / Regs
P03 - Contingency Mngmt
P04 - NextGen Compatibility



I01 - Airport Infrastructure
I02 - Airspace Infrastructure
I03 - Low-Alt. Traffic Mngmt
I04 - RF Spectrum
I05 - Test Ranges and LVC

S01 - Safety Criteria & MOCs
S02 - Cyber & Physical Security
S03 - Legal
S04 - Privacy
S05 - Noise

Each AI Enabler Category is comprised of several AI Enablers.
Each AI Enabler is comprised of several unique gaps and challenges.

AI Enabler Descriptions

Technology & Standards

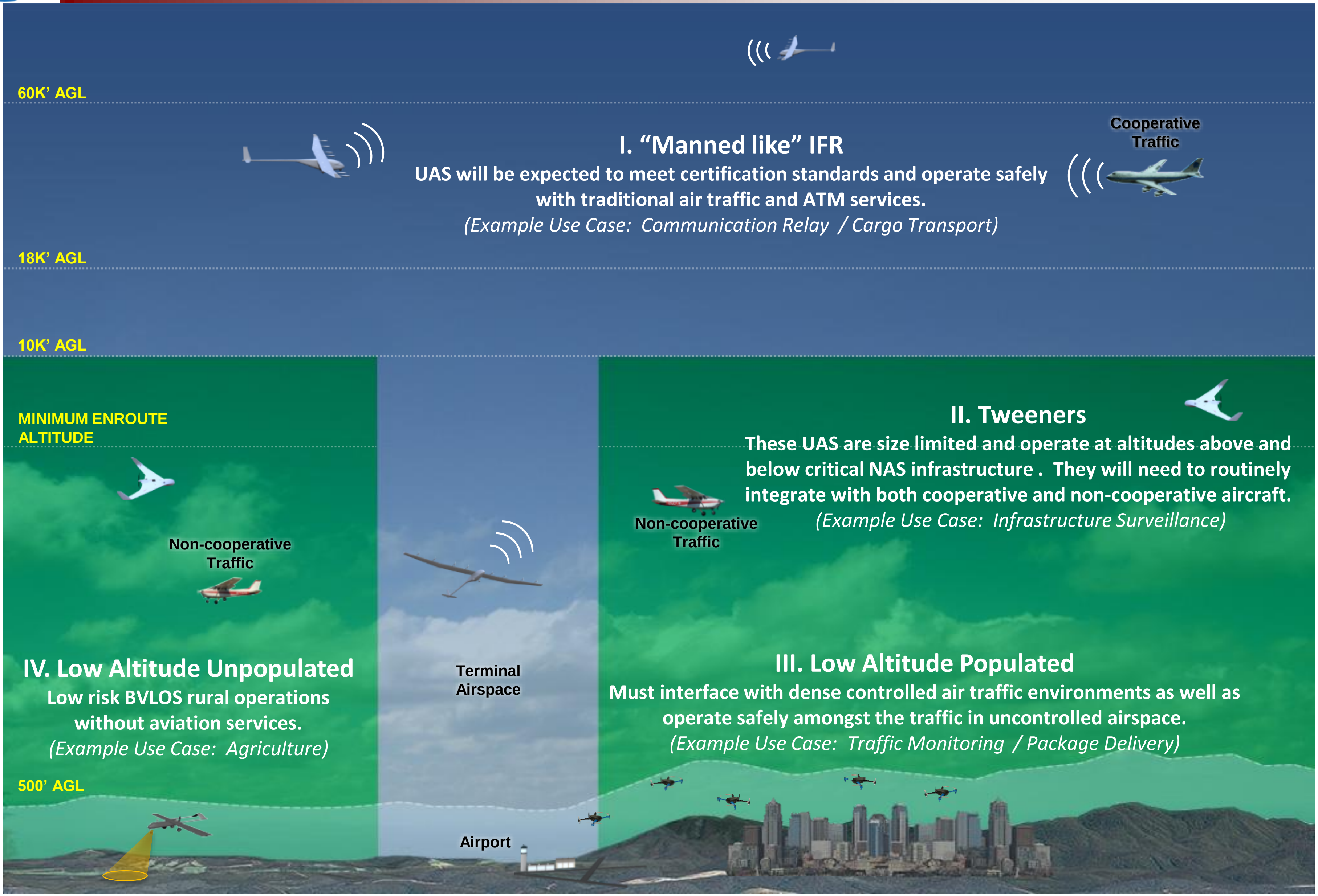
Airspace Integration Enablers			AI Enabler Description
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	Airport surface technologies, both on-board and off-board, need to be developed, validated and certified to safely and efficiently land, taxi and take-off from UAS accommodating airports.
	T02	Certifiable DAA Technologies	DAA technologies for tracking and avoiding collisions with other aircraft in all classes of airspace need to be developed, validated, and certified in accordance with the established requirements and standards to enable safe operations within the NAS.
	T03	Certifiable Hazard Avoidance Technologies	Hazard Avoidance technologies for avoiding collisions with obstacles and terrain need to be developed, validated, and certified in accordance with the established requirements and standards to enable safe low-altitude operations.
	T04	Certifiable C3 Technologies	C3 technologies need to be developed and certified in accordance with the established requirements and standards to enable safe and secure command & control, ATC communications, and BVLOS operations.
	T05	Certifiable GCS Technologies	GCS technologies, interfaces and displays need to be developed, validated and certified for various types (man-in-the-loop, man-on-the-loop, autonomous) of unmanned systems.
	T06	Certifiable Flight & Health Mngmt Systems	Technologies need to be developed that enable the measuring of key flight status and system health parameters, assessing their current condition, predicting their future condition, and informing others within the airspace.
	T07	Airworthiness Criteria / Standards / MOCs	Airworthiness C/S/M need to be developed for both large and small UAS with varying levels of autonomy. Published design criteria handbook, FAA Orders & Advisory Circulars for unmanned fixed-wing, rotorcraft & airships
	T08	Certifiable Navigation Technologies	Navigation technologies to support the level of fidelity needed for safe UAS operations need to be developed, validated, and certified.
	T09	Certifiable Weather Avoidance Technologies	Weather detection and avoidance/mitigation technologies need to be developed, validated and certified.
	T10	Certifiable Power & Propulsion Technologies	Power and propulsion technologies that increase safety, improve vehicle reliability, and increase endurance need to be developed, validated and certified.
	T11	Autonomous Architectures	Autonomous architectures for highly complex functions need to be developed, validated and certified.
	T12	Human Factors Guidelines	Human Factors guidelines and standards for UAS pilot and ATM displays (informative, suggestive, directive) need to be established.

AI Enabler Descriptions

Policy, Proc., NextGen / Infrastructure & Capabilities / Social Considerations

Airspace Integration Enablers			AI Enabler Description
Policies, Procedures & NextGen	P01	Airspace Mngmt Policies & Procedures	Airspace management policies and procedures for UAS operations within all classes of airspace need to be developed and adopted.
	P02	Operating Rules / Regs / Procedures	Rules / Regs / Procedures for UAS operations need to be developed and adopted . FAA Orders, Advisory Circulars (AC), AIM, Pilot/Crew Quals, Training & Medical requirements for UAS need to be developed and published.
	P03	Contingency Mngmt Procedures	Guidelines for contingency planning and handling need to be developed and published for all levels of autonomy (man-in-the-loop, man-on-the-loop, autonomous) and classes of airspace.
	P04	NextGen Compatibility	Certain UAS must be properly equipped to ensure compatibility with NextGen so as to not degrade the safety or efficiency of the NAS.
Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	Airport infrastructure improvements are necessary to accommodate UAS operations, while still ensuring the ops tempo and safety record of airports today.
	I02	UAS Accommodating Airspace Mngmt Infrastructure	The current and future Air Traffic Management (ATM) system will need to be modified to accommodate UAS operations while still maintaining the safety and efficiency of the NAS.
	I03	Low-Altitude Airspace Mngmt Infrastructure	Airspace infrastructure needs maturation to manage increased capacity in densely populated airspace and at low altitudes without degrading safety and efficiency.
	I04	Adequate Secured / Managed RF Spectrum	Adequate RF Spectrum for UAS command and control and payload applications still needs to be defined and secured through the FCC and WRC.
	I05	Sufficient Test Ranges and LVC M&S Facilities	Sufficient UAS Test Ranges and Live Virtual Constructive (LVC) Modeling & Simulation facilities need to be established and available for UAS testing and evaluation.
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	Safety requirements and standards need to be established for all types of UAS operations in all classes of airspace.
	S02	Cyber & Physical Security Criteria & MOCs	Robust cybersecurity guidelines for identifying and mitigating potential cyber threats as well as criteria and techniques for ensuring the physical security of vital assets are needed to ensure overall mission assurance and public trust.
	S03	Legal Framework for UAS Litigation	Legal framework needs to be established for UAS-related litigation.
	S04	Privacy Guidelines & Rules	Privacy guidelines and rules need to be established for large and small UAS.
	S05	Noise Guidelines & Rules	Noise guidelines and rules need to be established for large and small UAS.

Emerging Commercial UAS Operational Environments (OE)



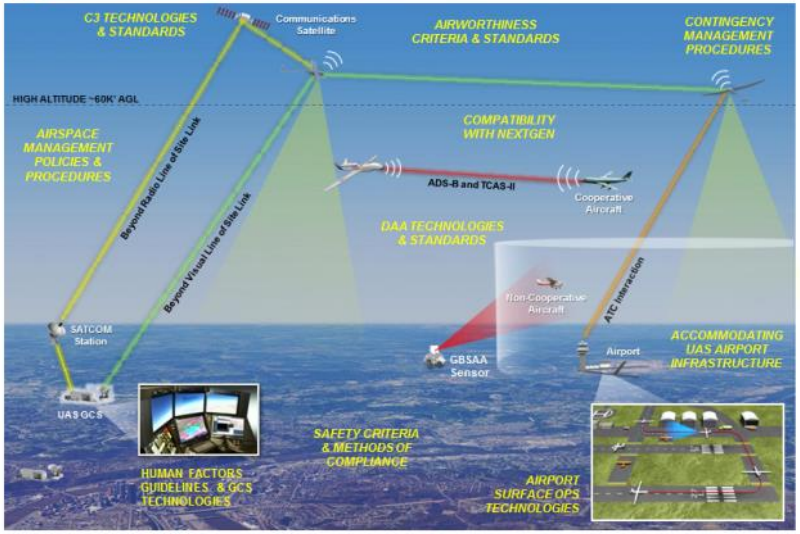
Operational Environment Attributes

Representative Operational Environments		Example Use Cases	Operational Environment Attributes
I	"Manned like" IFR	Communication Relay & Cargo Transport	Aircraft will operate in similar fashion to current manned aircraft on the airport surface and during flight. Enabling technologies such as DAA, C3, GCS, and flight management systems will have standards validated through robust integrated simulations and flight tests.
II	Tweeners	Large Infrastructure Inspection	Aircraft will operate in a mixed environment with both participating and non-participating aircraft. Operations will be BVLOS and BRLOS, so onboard equipage will be required. Enabling technologies such as DAA, C3, and navigation systems will be critical, but other challenges for low swap systems and interoperability with current NAS infrastructure will be addressed through risk-based certification. Privacy, noise, and security concerns will become more challenging.
III	Low Altitude Populated	Package Delivery & Traffic Monitoring	High numbers of aircraft will operate in both controlled and uncontrolled airspace. The operations will be interoperable with manned aircraft and the Air Traffic Management system. Performance-based operations may include reliable hazard avoidance, C3, navigation, and autonomy, teaming. Significant social considerations for noise, security, privacy, and land rights will be addressed.
IV	Low Altitude Unpopulated	Agriculture	Operations will be low risk, but some flights will require a minimum capability set that may include reliable hazard avoidance, C3, navigation, and autonomy. Privacy, noise, and security concerns will become more challenging.

Representative Operational Environments

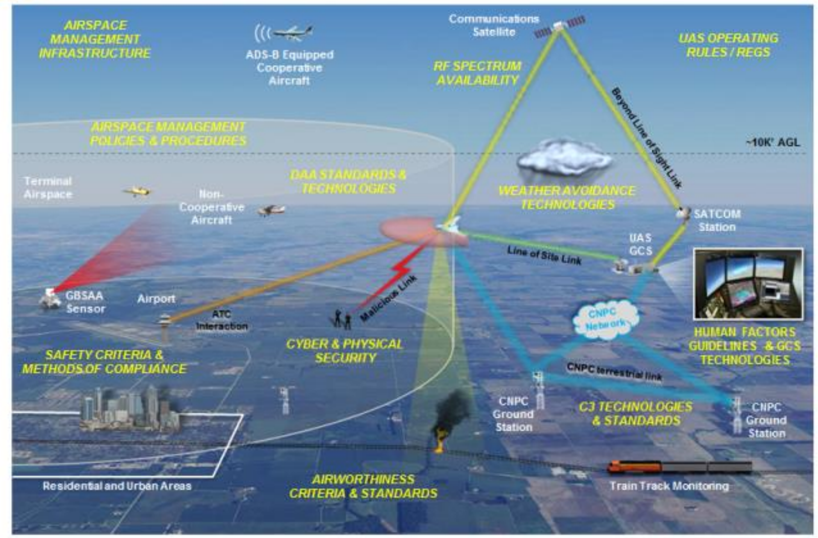
Type I: “Manned like” Operations

Example Use Case: Communication Relay and Cargo Transport



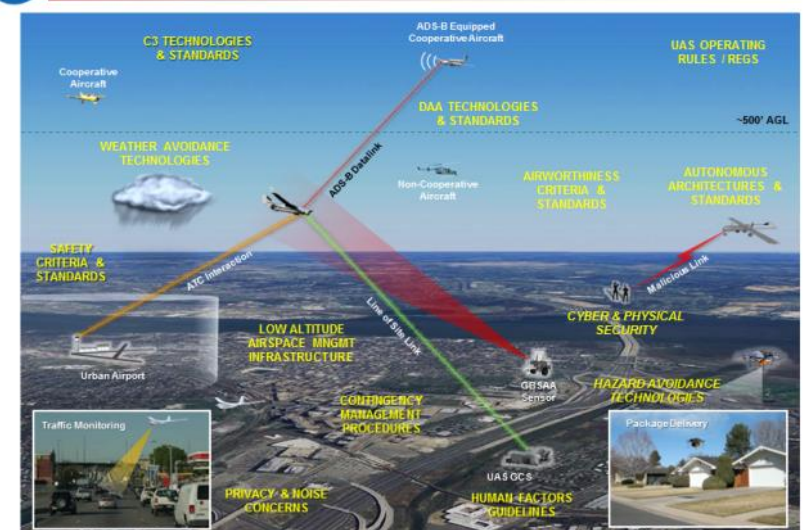
Type II: Tweeners

Example Use Case: Large Infrastructure Surveillance



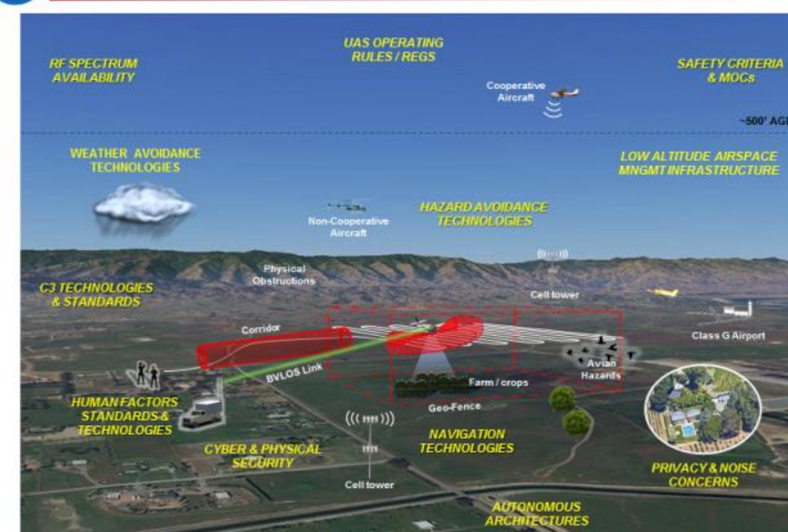
Type III: Low Altitude Populated

Example Use Case : Package Delivery/Traffic Monitoring



Type IV: Low Altitude Unpopulated

Example Use Case : Agricultural



Relationship between Airspace Integration Enablers & Operational Environments

Airspace Integration Enablers			Operational Environment			
			"Manned Like" IFR (I)	Tweener (II)	Low-Alt / Populated (III)	Low-Alt / Unpopulated (IV)
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	X	-	-	-
	T02	Certifiable DAA Technologies	X	X	X	-
	T03	Certifiable Hazard Avoidance Technologies	-	X	X	-
	T04	Certifiable C3 Technologies	X	X	X	X
	T05	Certifiable GCS Technologies	X	X	X	-
	T06	Certifiable Flight & Health Mngmt Systems	X	X	X	-
	T07	Airworthiness Criteria / Standards / MOCs	X	X	X	X
	T08	Certifiable Navigation Technologies	-	X	X	X
	T09	Certifiable Weather Avoidance Technologies	-	X	X	X
	T10	Certifiable Power & Propulsion Technologies	-	-	-	-
	T11	Autonomous Architectures	X	X	X	-
	T12	Human Factors Guidelines	X	X	X	-
Policies, Procedures & NextGen	P01	Airspace Mngmt Policies & Procedures	X	X	X	-
	P02	Operating Rules / Regs / Procedures	X	X	X	-
	P03	Contingency Mngmt Procedures	X	X	X	X
	P04	NextGen Compatibility	X	X	-	-
Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	X	-	-	-
	I02	UAS Accommodating Airspace Mngmt Infrastructure	X	X	-	-
	I03	Low-Altitude Airspace Mngmt Infrastructure	-	-	X	X
	I04	Adequate Secured / Managed RF Spectrum	-	X	X	X
	I05	Sufficient Test Ranges and LVC M&S Facilites	-	X	X	-
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	X	X	X	X
	S02	Cyber & Physical Security Criteria & MOCs	X	X	X	X
	S03	Legal Framework for UAS Litigation	-	-	X	X
	S04	Privacy Guidelines & Rules	-	X	X	X
	S05	Noise Guidelines & Rules	-	-	X	X

Note: The "X" designation indicates that this AI Enabler is very important for achieving full Integration within this Operational Environment.

Cost, Opportunity, Benefit, Risk Evaluation Criteria

***Cost*: Resources required to achieve the desired outcome**

– Costs needed to *develop the solution* necessary to close the gap
– Costs needed to *implement the change* needed to close the gap

***Opportunity*: Ability to accelerate schedule, reduce costs, and leverage other's efforts**

– Opportunity to accelerate implementation schedule
– Opportunity to collaborate or partner with others to reduce cost
– Opportunity to leverage existing technologies and efforts

***Benefit*: Overall contribution towards achieving Full Integration**

– Relative benefit to the civil/commercial UAS market as a result of closing the gap

***Risk*: Negative effects resulting from not achieving the desired outcome**

– Inability to reduce the size/complexity of the gap or implementation difficulty
– Unrealized civil/commercial UAS market
– Delay in achieving full integration
– Adversely impact the safety and efficiency of the NAS

Opportunity & Risk Evaluation Criteria

Proposed Criteria and Weighting Values

Categories	Weighting	Criteria Definitions
Opportunity: Ability to accelerate schedule, reduce costs, and leverage other's efforts		
Opportunity to Accelerate the Implementation Schedule	**35%**	**How much time can be saved based on clarity/efficiency of the implementation path?**
	High	A well-defined implementation path allows for the opportunity to accelerate tasks & maximize sched. efficiency
	Med	An implementation path is only partially or generally defined, reducing the ability to accelerate the schedule
	Low	An implementation path is not defined, minimizing any opportunity to accelerate the schedule
Opportunity to Collaborate / Partner with Others	**35%**	**How great is the opportunity to collaborate with other organizations to leverage resources and efforts?**
	High	There are several potential partners available and interested in collaborating
	Med	There are a moderate number of potential partners available to collaborate with
	Low	Very few, if any, partners are known or available to collaborate with
Opportunity to Leverage Existing Technologies & Efforts	**30%**	**How can we "move up the starting line" by leveraging work already being done in other fields?**
	High	There are significant opportunities to leverage existing and/or emerging technologies
	Med	There are moderate opportunities to leverage existing and/or emerging technologies
	Low	There are minimal opportunities to leverage existing and/or emerging technologies

Categories	Weighting	Criteria Definitions
Risk: Negative effects resulting from not achieving the desired outcome		
Inability to reduce the Size & Complexity needed to close the Gap	**35%**	**How great is the size/complexity of the gap, to include the difficulty of implementation?**
	High	The Gap size, complexity, and difficulty of implementation is *significant*
	Med	The Gap size, complexity, and difficulty of implementation of the Gap is *moderate*
	Low	The Gap size, complexity, and difficulty of implementation of the Gap is *minimal*
Unrealized Civil / Commercial UAS Market	**30**	**How will failure to address this gap impact the Civil/Commercial economic outlook?**
	High	Failure to close the Gap will *significantly* impact the ability to realize a Civil/Commercial UAS Market
	Med	Failure to close the Gap will *moderately* impact the ability to realize a Civil/Commercial UAS Market
	Low	Failure to close the Gap will *minimally* impact the ability to realize a Civil/Commercial UAS Market
Delay in Achieving Full Integration	**20%**	**How will failure to address this gap impact the critical path for full integration?**
	High	Failure to close this Gap will *significantly* delay the date full integration can be achieved
	Med	Failure to close this Gap will *moderately* delay the date full integration can be achieved
	Low	Failure to close this Gap will *minimally* delay the date full integration can be achieved
Adversely Impact the Safety and Efficiency of the NAS	**15%**	**How will failure to address this gap impact the efficiency of the NAS, without degrading safety?**
	High	Failure to close this Gap will *significantly* decrease the overall safety and efficiency of the NAS
	Med	Failure to close this Gap will *moderately* decrease the overall safety and efficiency of the NAS
	Low	Failure to close this Gap will *have little impact* on the overall safety and efficiency of the NAS

Benefit & Cost Evaluation Criteria

Proposed Criteria and Weighting Values

Categories	Weighting	Criteria Definitions
Cost: Resources required to achieve the desired outcome		
Gap Solution Development Cost	**50%**	**Required resources to *develop* the solution(s) to close the Gap leading to Full Integration**
	Very High	*Very significant* resources required to solve the remaining Gap (>$1B)
	High	*Significant* resources required to solve the remaining Gap ($100M-$1B)
	Med	*Moderate* resources required to solve the remaining Gap ($10M-$100M)
	Low	*Minimal* resources required to solve the remaining Gap ($1M-$10M)
	Very Low	*Very minimal* resources required to solve the remaining Gap (<$1M)
Gap Solution Implementation Cost	**50%**	**Required resources to *implement* the solution(s) to close the Gap leading to Full Integration**
	Very High	*Very significant* resources required to implement the solution (>$1B)
	High	*Significant* resources required to implement the solution ($100M-$1B)
	Med	*Moderate* resources required to implement the solution ($10M-$100M)
	Low	*Minimal* resources required to implement the solution ($1M-$10M)
	Very Low	*Very minimal* resources required to implement the solution (<$1M)

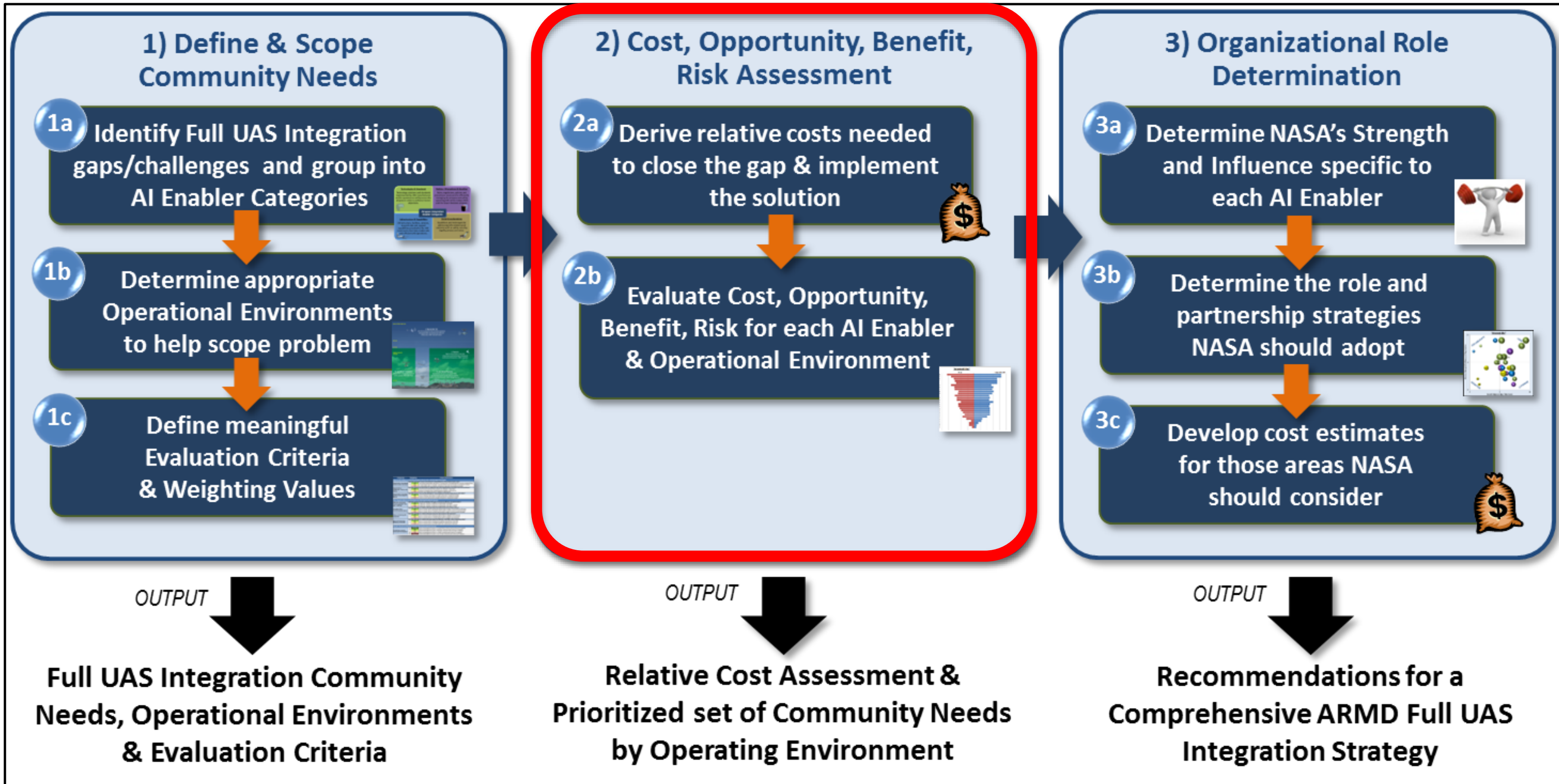
Benefit: Overall contribution towards achieving Full Integration		
Relative contribution towards achieving Full Integration	Very High	Making progress against this Gap will *very significantly* contribute towards achieving full integration
	High	Making progress against this Gap will *significantly* contribute towards achieving full integration
	Med	Making progress against this Gap will *moderately* contribute towards achieving full integration
	Low	Making progress against this Gap will *minimally* contribute towards achieving full integration
	Very Low	Making progress against this Gap will *very minimally* contribute towards achieving full integration

COBRA Score = [(O1 x Ow1) + (O2 x Ow2) + (O3 x Ow3)] B + [(R1 x Rw1) + (R2 x Rw2) + (R3 x Rw3) + (R4 x Rw4)] B

where: O = Opportunity score, Ow = Opportunity weight, R = Risk score, Rw = Risk weight, B = Benefit score

Total Cost Score = (Cd x Cdw) + (Ci x Ciw)

where: Cd = Relative cost to develop solution, Ci = Relative cost to implement solution, Cdw = Devpmt. cost weight, Ciw = Imp. cost weight



STEP 2: COST, OPPORTUNITY, BENEFIT, RISK ASSESSMENT

Decision Support Tool Attributes

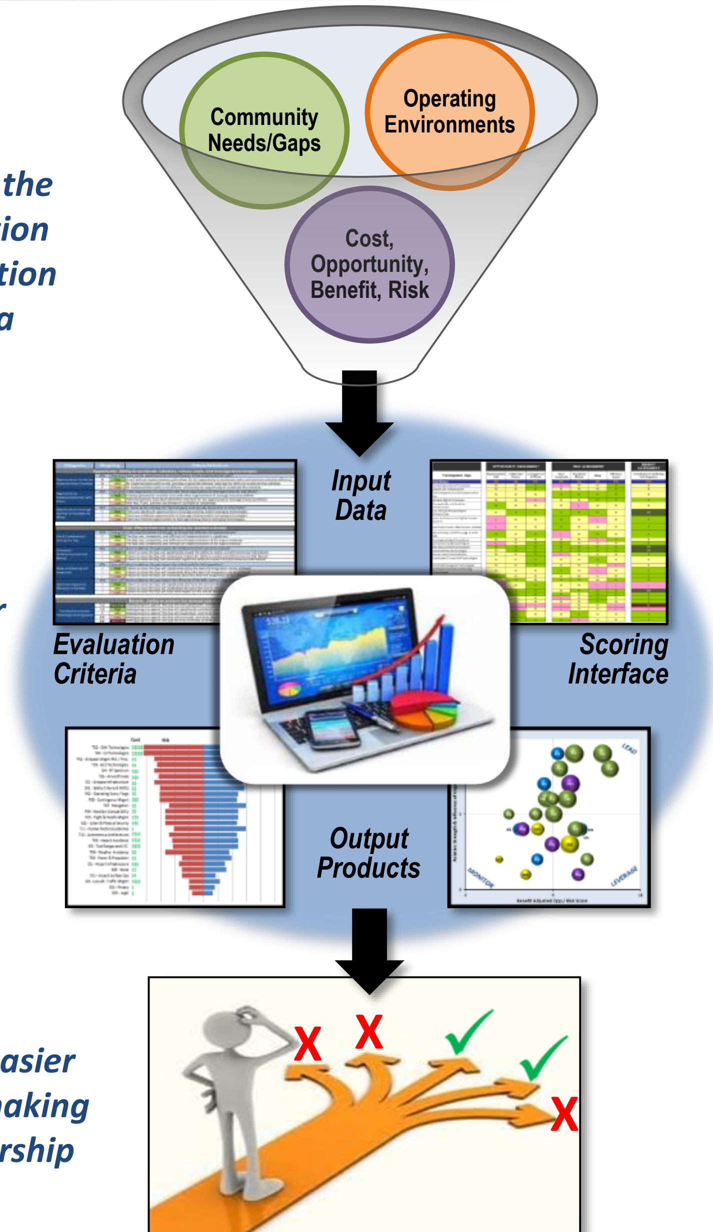
- A decision support tool should be developed in accordance with the UAS Full Integration Analytical Framework
  - Considers merits of all ***community needs, gaps and challenges***
  - Accounts for unique ***operating environments, CONOPs*** and ***Use Cases***
  - Evaluates the associated ***costs, opportunities, benefits*** and ***risks***

- Tool helps guide the analysis by:
  - Capturing the evaluation criteria and weighting values
  - Providing an interface for scoring
  - Supporting operational analysis efforts to identify trends and research findings
  - Developing meaningful products that can be used by leadership to help make decisions

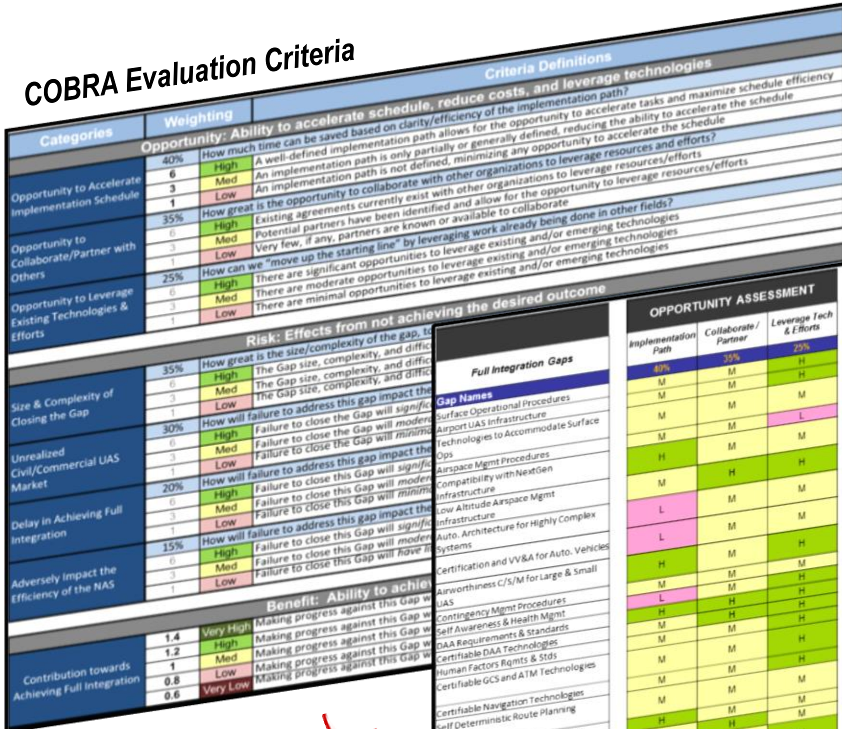
Facilitates the consolidation of information and data

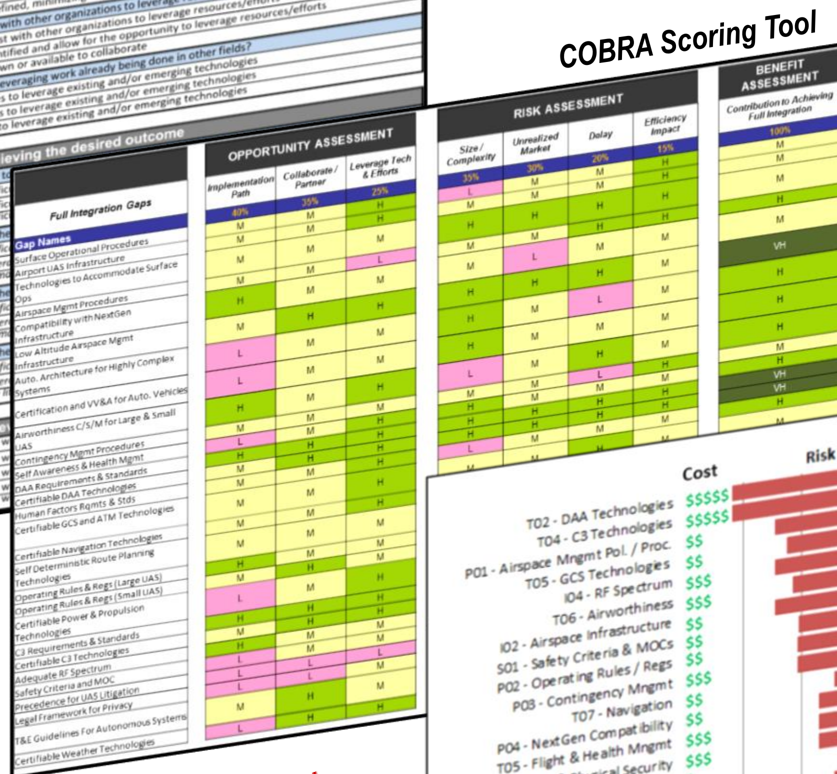
Provides a mechanism for performing analysis in a structured manner

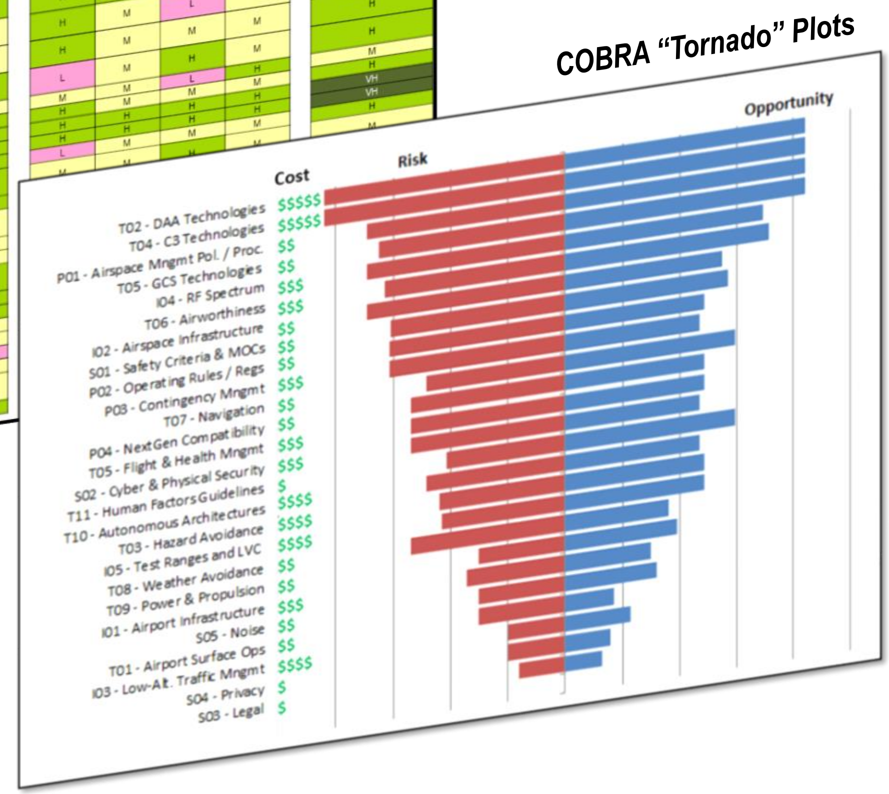
Enables easier decision making for Leadership



Cost, Opportunity, Benefit, Risk Assessment (COBRA) Process







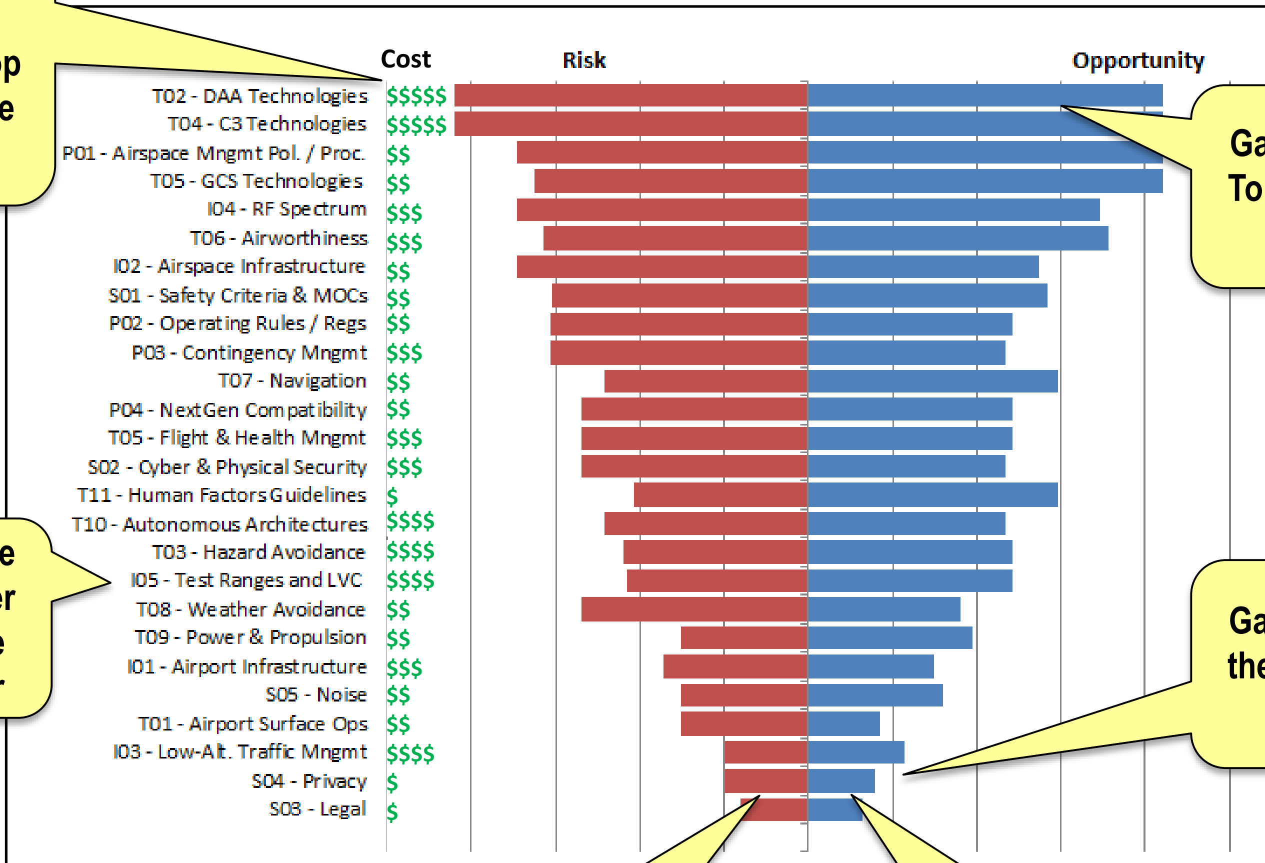
Use COBRA Evaluation Criteria to score each AI Enabler

Generate COBRA Tornado Plots for each Operational Environment to reveal each gap's overall importance to Full Integration

How to Read a COBRA Tornado Plot

Notional Plot

Relative costs required to develop and implement the solution



Gaps at the top of the Tornado Plot have the highest score

Individual Airspace Integration Enabler name with unique 3-digit designator

Gaps at the bottom of the Tornado Plot have the lowest score

Legend:
T = Technology & Standards
P = Policy, Procedures & NextGen
I = Infrastructure & Capabilities
S = Social Considerations

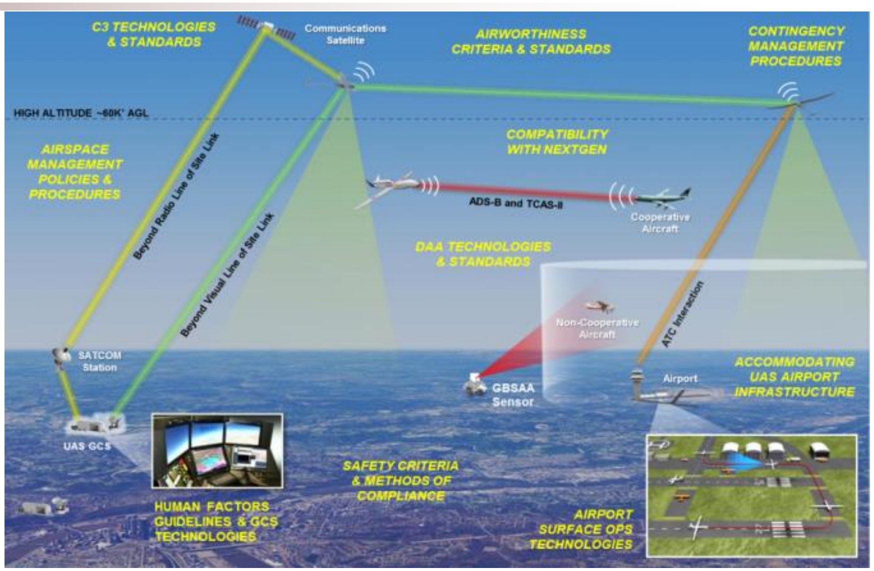
Red bar indicates the total Risk resulting from not successfully addressing the gap

Blue bar indicates the total Opportunity if the gap is addressed

Airspace Integration Enablers
I. “Manned-like” IFR

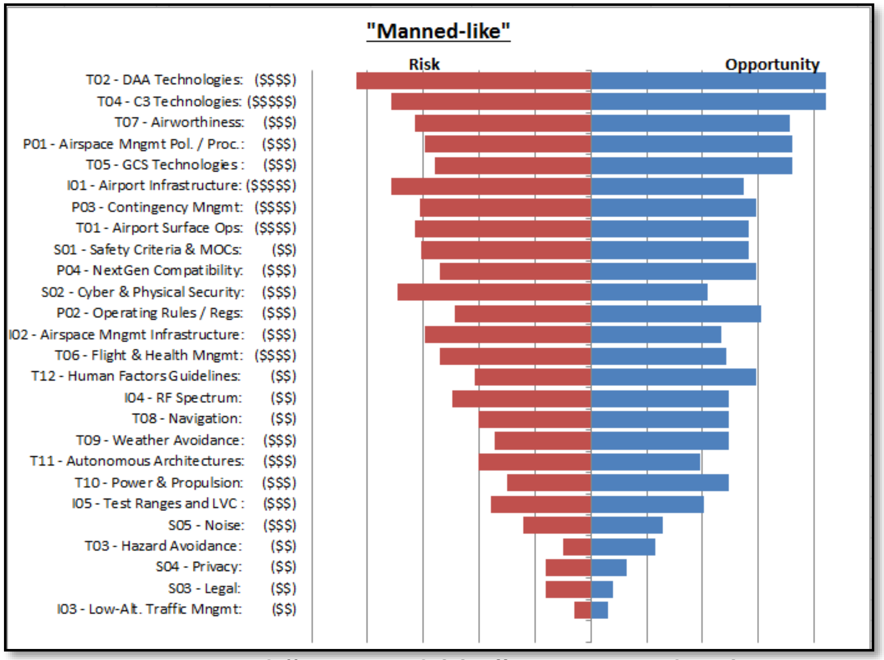
Operational Concept: Aircraft will operate in similar fashion to current manned aircraft on the airport surface and during flight. Enabling technologies such as DAA, C3, GCS, and flight management systems will have standards validated through robust integrated simulations and flight tests.

Key Finding: Operational concepts are well understood, and many of the technologies are at high TRL levels.



Tornado Plot “Top 10”:

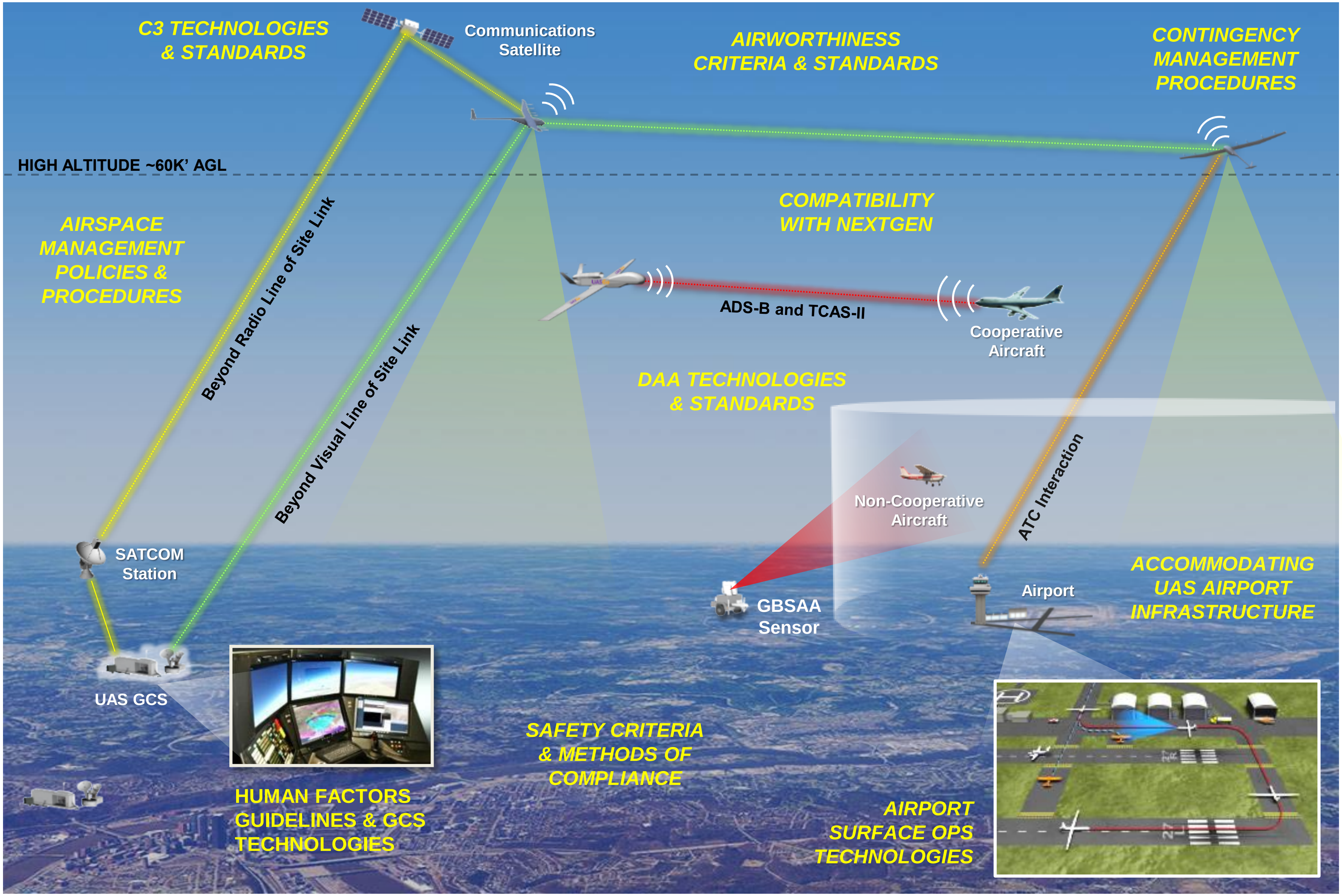
AI Enabler	COBRA Score
T02 - DAA Technologies: ($$$$)	**16.8**
T04 - C3 Technologies: ($$$$$)	**15.5**
T07 - Airworthiness: ($$$)	**13.4**
P01 - Airspace Mngmt Pol. / Proc.: ($$$)	**13.1**
T05 - GCS Technologies : ($$$)	**12.8**
I01 - Airport Infrastructure: ($$$$$)	**12.6**
P03 - Contingency Mngmt: ($$$$)	**12.1**
T01 - Airport Surface Ops: ($$$$)	**12.0**
S01 - Safety Criteria & MOCs: ($$)	**11.8**
P04 - NextGen Compatibility: ($$$)	**11.3**



Prioritized “Manned-like” IFR Tornado Plot

Type I: “Manned like” Operations

Example Use Case: Communication Relay and Cargo Transport



Airspace Integration Enablers

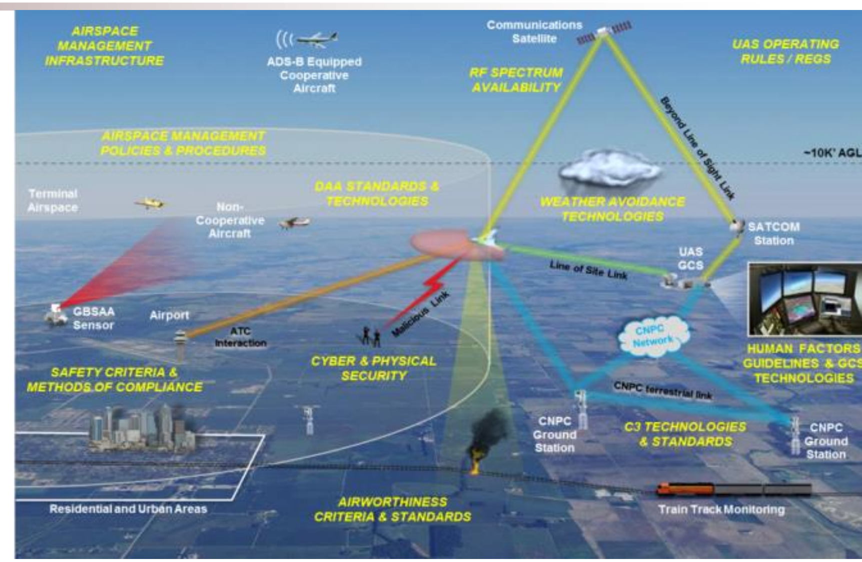
II. Tweeners

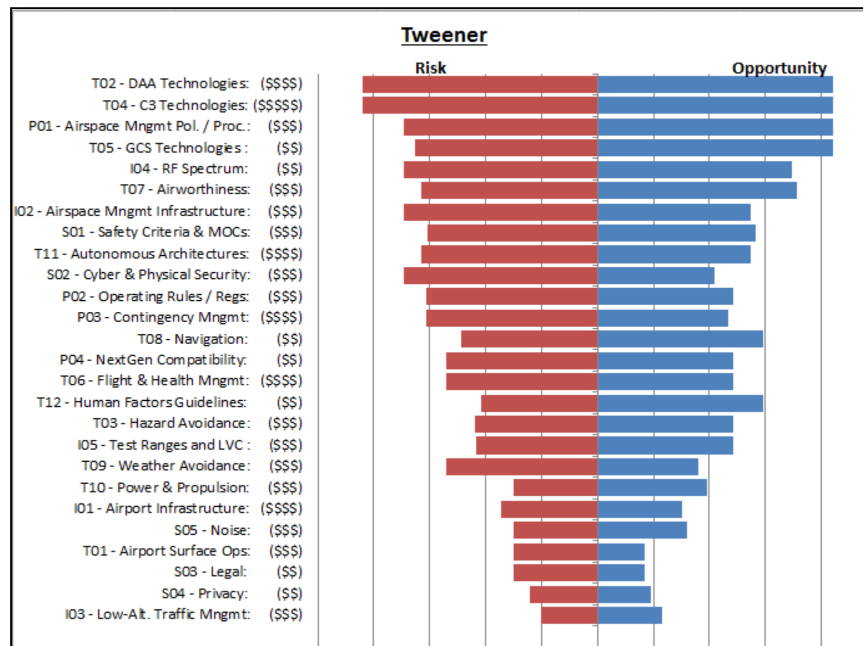
Operational Concept: Aircraft will operate in a mixed environment with both participating and non-participating aircraft. Operations will be BVLOS and BRLOS, so onboard equipage will be required. Enabling technologies such as DAA, C3, and navigation systems will be critical, but other challenges for low swap systems and interoperability with current NAS infrastructure will ne addressed through risk-based certification. Privacy, noise, and security concerns will become more challenging.

Key Finding: Operational concepts are well understood, but many of the technologies are at low TRL levels. Since flights will operate in a mixed environment that is both BVLOS and BRLOS, many technologies must be on board. This introduces additional low SWAP constraints making Tweeners very challenging.

Tornado Plot "Top 10":

AI Enabler	COBRA Score
T02 - DAA Technologies: ($$$$)	16.8
T04 - C3 Technologies: ($$$$$)	16.8
P01 - Airspace Mngmt Pol. / Proc.: ($$$)	15.3
T05 - GCS Technologies : ($$)	14.9
I04 - RF Spectrum: ($$)	13.9
T07 - Airworthiness: ($$$)	13.4
I02 - Airspace Mngmt Infrastructure: ($$$)	12.4
S01 - Safety Criteria & MOCs: ($$$)	11.8
T11 - Autonomous Architectures: ($$$$)	11.8
S02 - Cyber & Physical Security: ($$$)	11.1

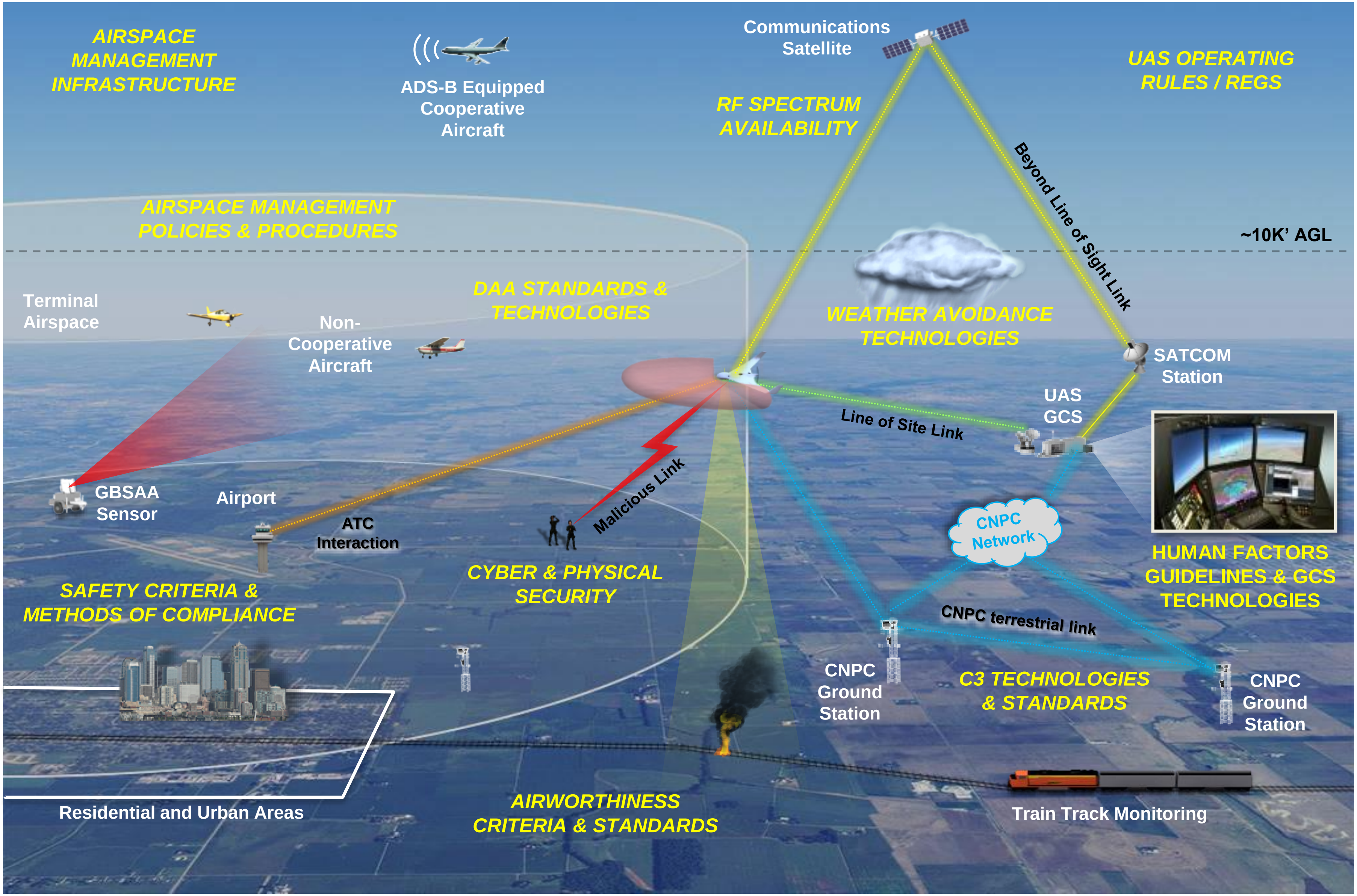




Prioritized Tweener Tornado Plot

Type II: Tweeners

Example Use Case: Large Infrastructure Surveillance

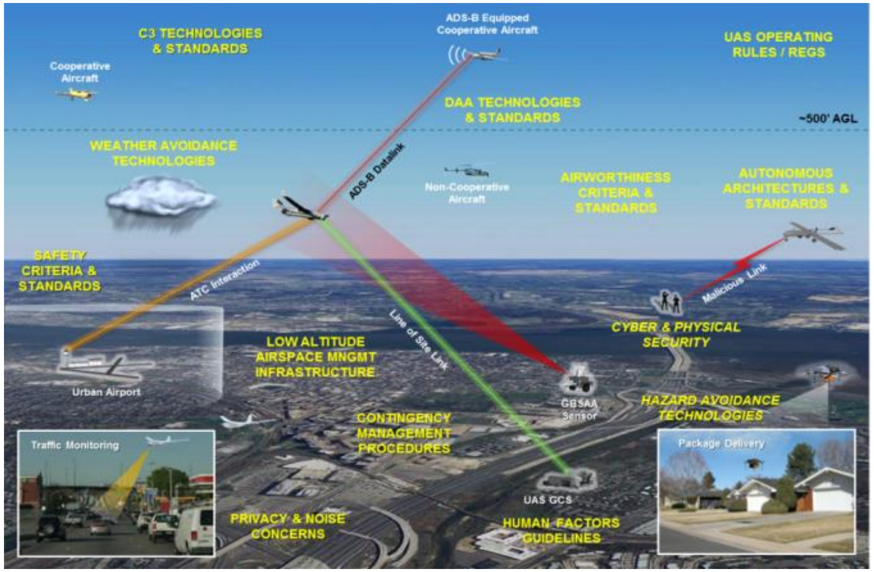


Airspace Integration Enablers

III. Low Altitude Populated

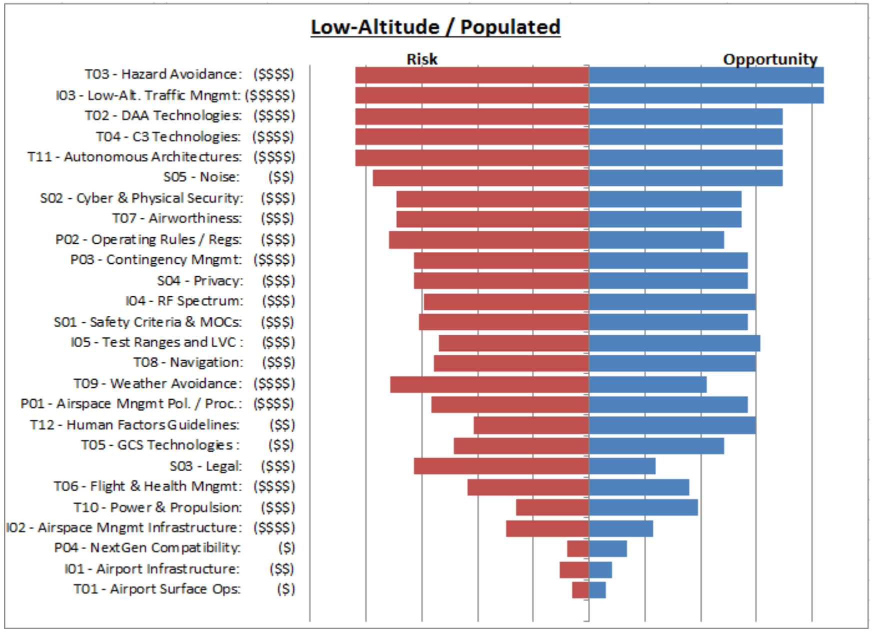
Operational Concept: High numbers of aircraft will operate in both controlled and uncontrolled airspace. The operations will be interoperable with manned aircraft and the Air Traffic Management system. Performance-based operations may include reliable hazard avoidance, C3, navigation, and autonomy, teaming. Significant social considerations for noise, security, privacy, and land rights will be addressed.

Key Finding: Operational concepts are well understood, but many of the technologies are at low TRL levels. Operations will be in a more controlled environment, but the technology challenges for managing large volumes of aircraft are still being developed. Significant gaps exist in vehicle technologies for operating at low altitudes in urban environments.



Tornado Plot "Top 10":

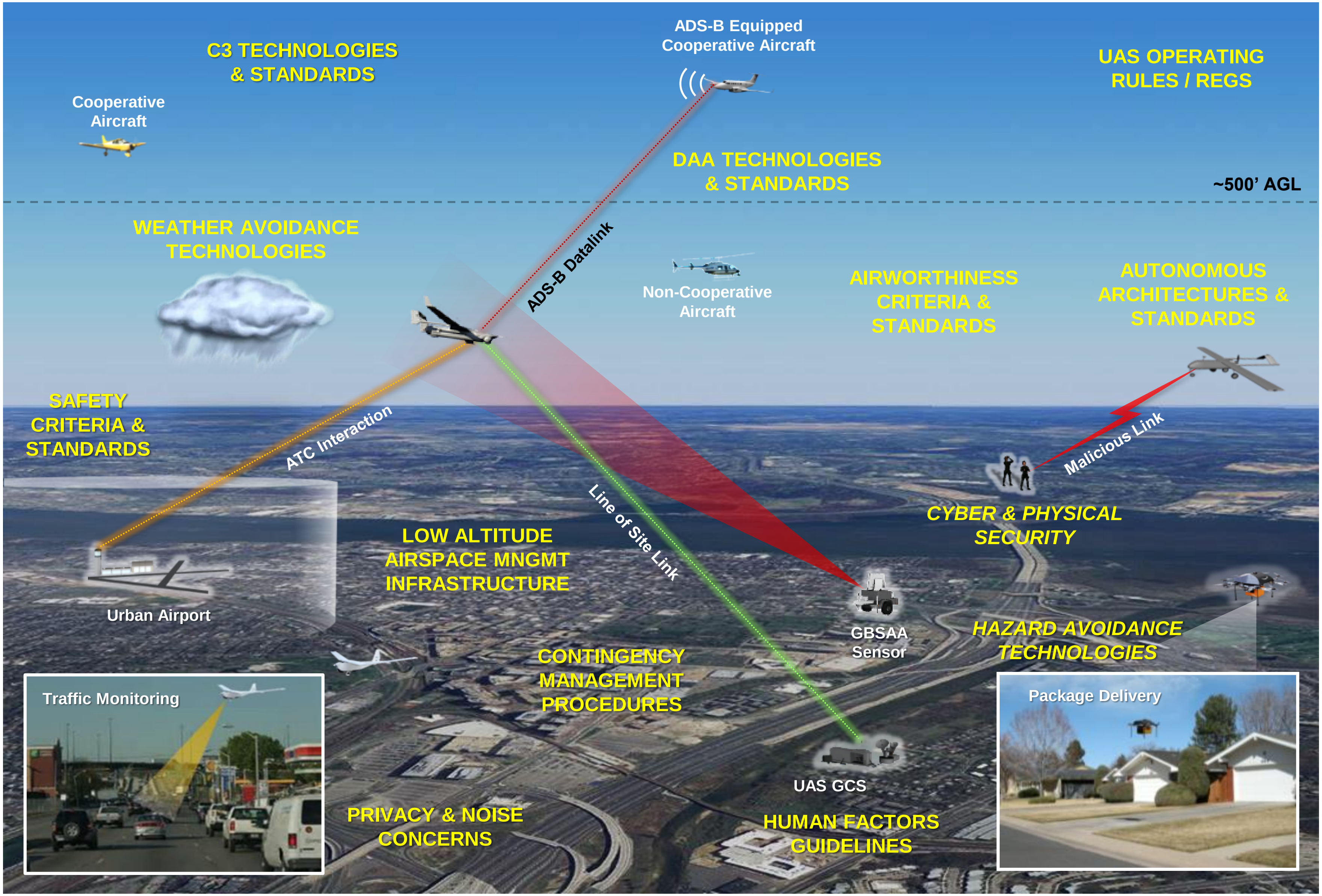
AI Enabler	COBRA Score
T03 - Hazard Avoidance: ($$$$)	**16.8**
I03 - Low-Alt. Traffic Mngmt: ($$$$$)	**16.8**
T02 - DAA Technologies: ($$$$)	**15.3**
T04 - C3 Technologies: ($$$$)	**15.3**
T11 - Autonomous Architectures: ($$$$)	**15.3**
S05 - Noise: ($$)	**14.7**
S02 - Cyber & Physical Security: ($$$)	**12.4**
T07 - Airworthiness: ($$$)	**12.4**
P02 - Operating Rules / Regs: ($$$)	**12.1**
P03 - Contingency Mngmt: ($$$$)	**12.0**



Prioritized Low Altitude Populated Tornado Plot

Type III: Low Altitude Populated

Example Use Case : Package Delivery/Traffic Monitoring

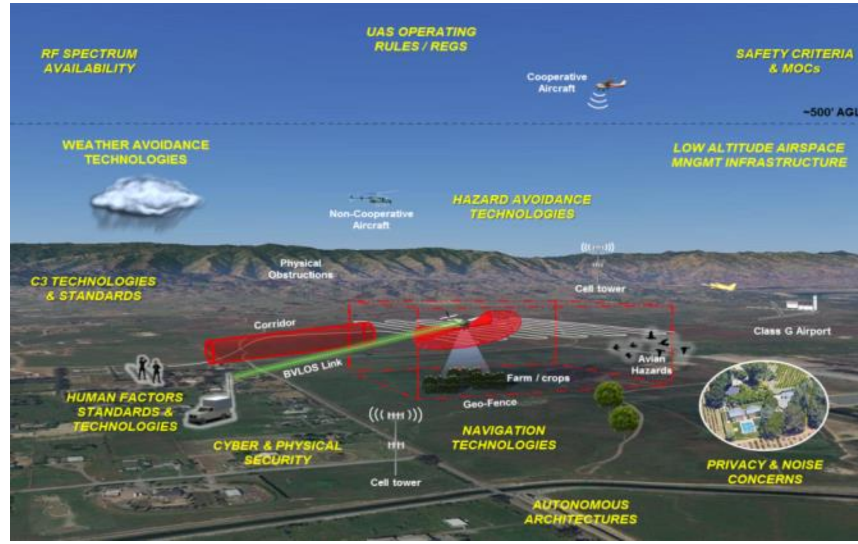


Airspace Integration Enablers

IV. Low Altitude Unpopulated

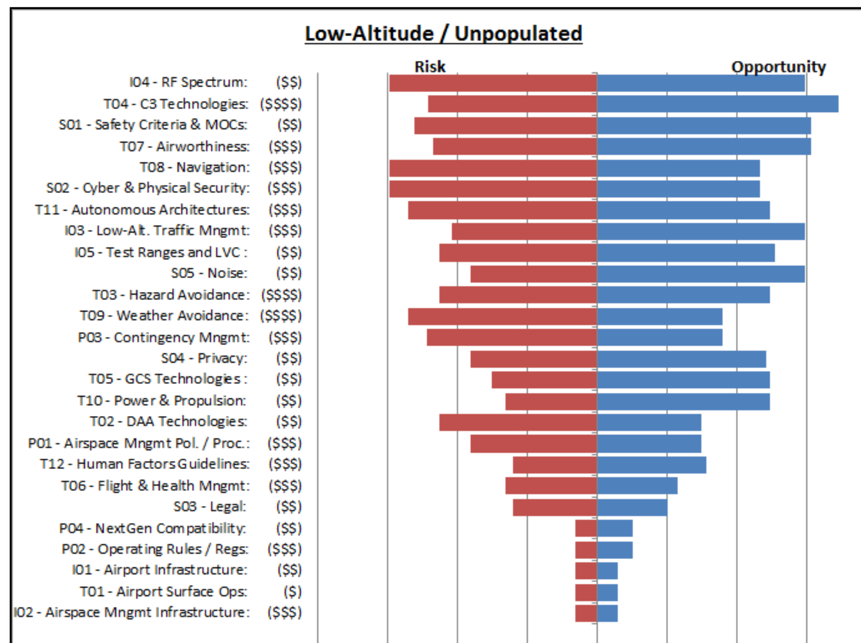
Operational Concept: Operations will be low risk, but some flights will require a minimum capability set that may include reliable hazard avoidance, C3, navigation, and autonomy. Privacy, noise, and security concerns will become more challenging.

Key Finding : Operational concepts are well understood, but many of the technologies are at low TRL levels. Operations will be in a more controlled environment, but the technology challenges for managing large volumes of aircraft are still being developed. Significant gaps exist in vehicle technologies for operating at low altitudes in urban environments.



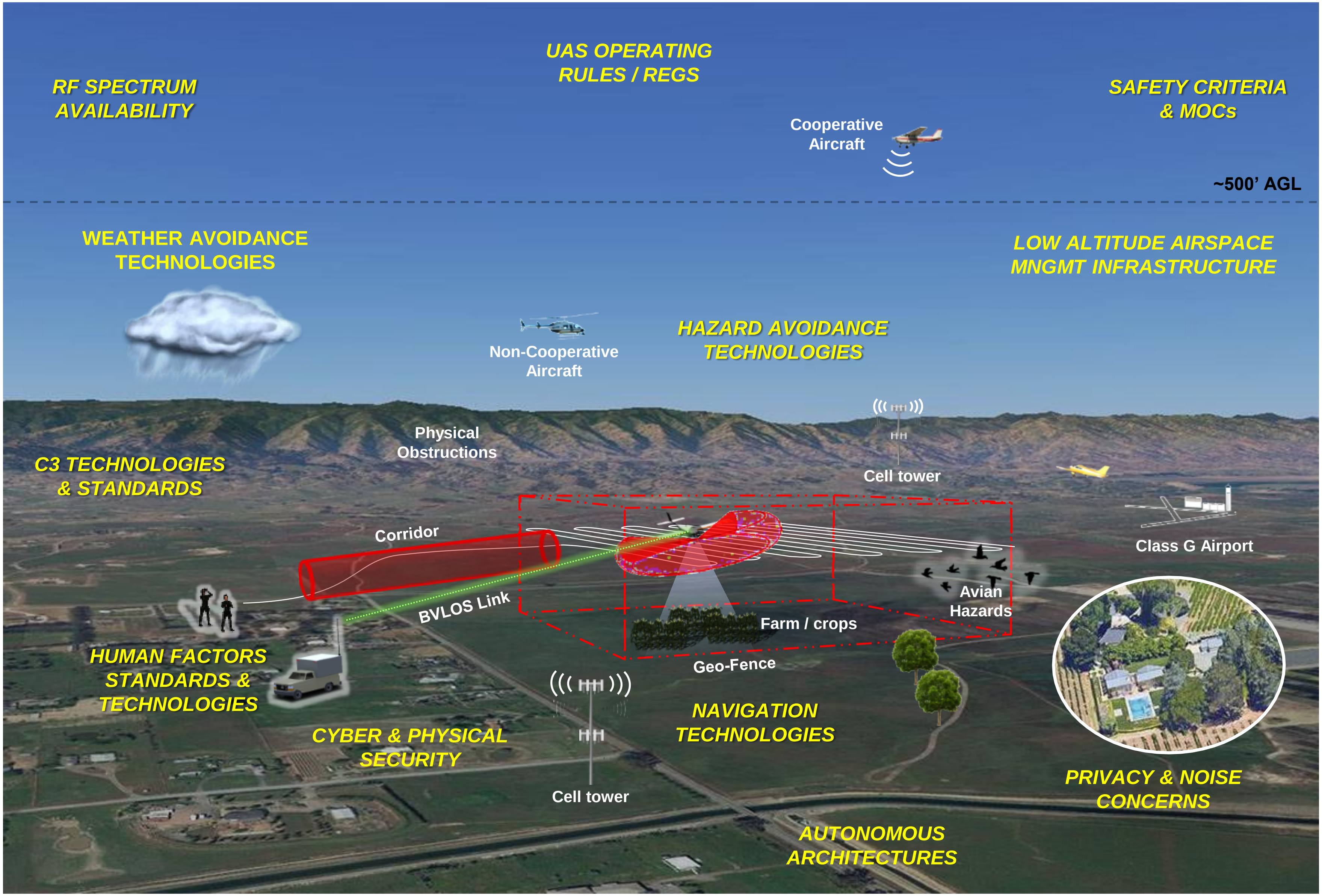
Tornado Plot "Top 10":

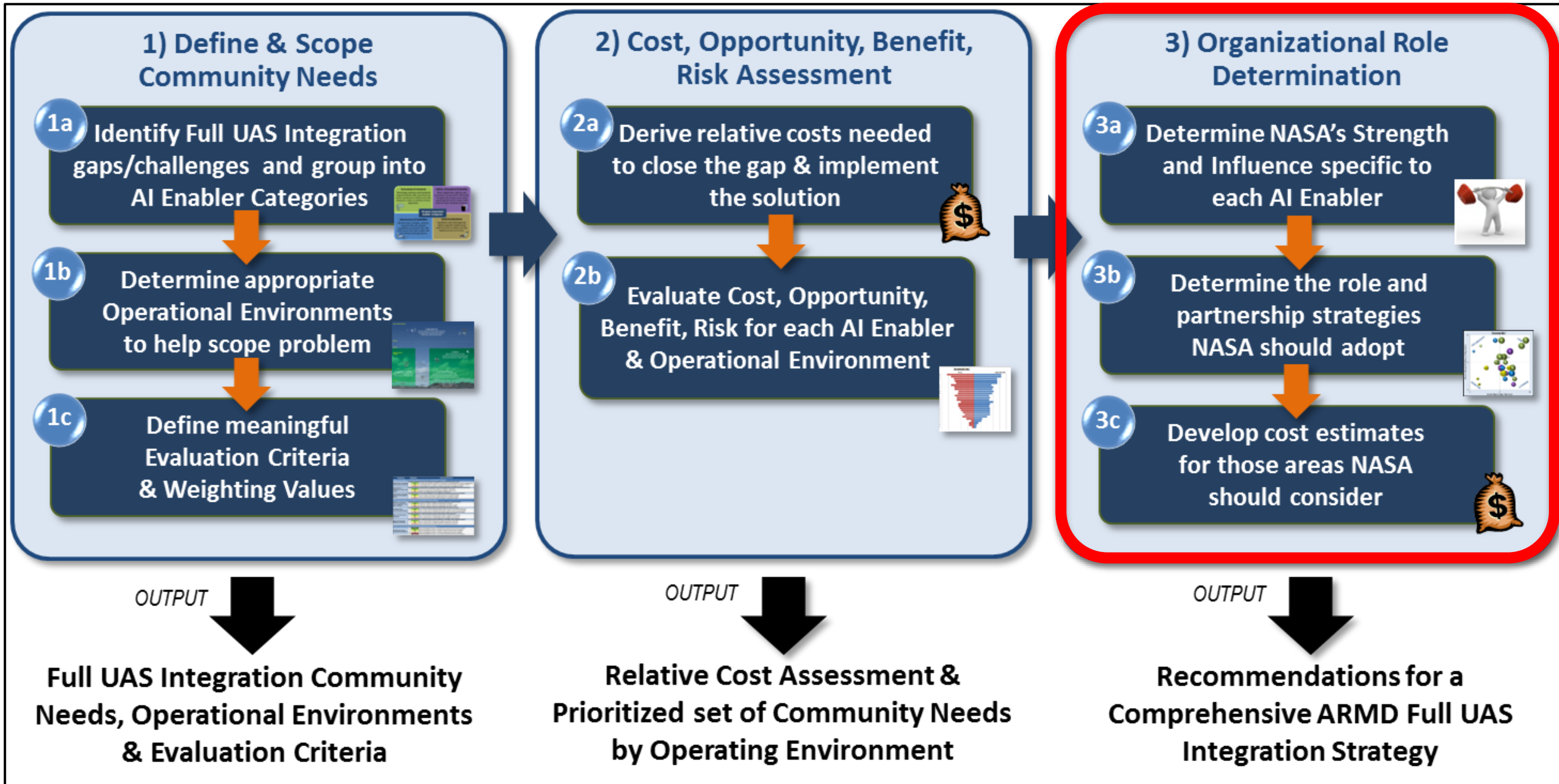
AI Enabler	COBRA Score
I04 - RF Spectrum: ($$)	**11.9**
T04 - C3 Technologies: ($$$$)	**11.8**
S01 - Safety Criteria & MOCs: ($$)	**11.3**
T07 - Airworthiness: ($$$)	**10.8**
T08 - Navigation: ($$$)	**10.6**
S02 - Cyber & Physical Security: ($$$)	**10.6**
T11 - Autonomous Architectures: ($$$)	**10.4**
I03 - Low-Alt. Traffic Mngmt: ($$$)	**10.1**
I05 - Test Ranges and LVC : ($$)	**9.6**
S05 - Noise: ($$)	**9.5**



Prioritized Low Altitude Unpopulated Tornado Plot

Type IV: Low Altitude Unpopulated
Example Use Case : Agricultural

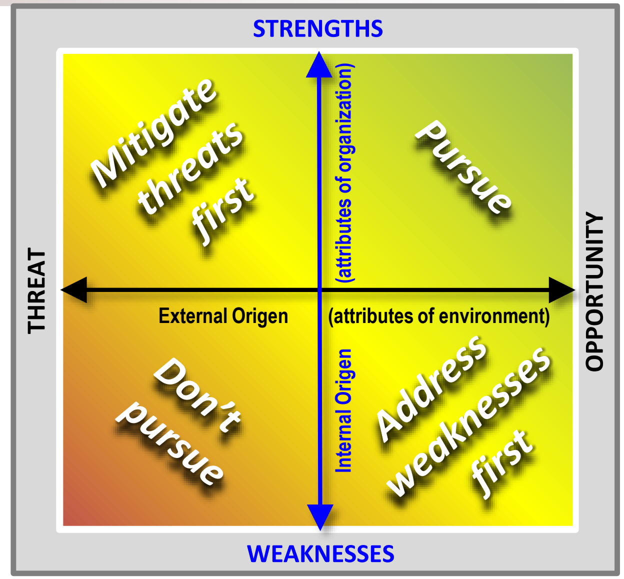




STEP 3: ORGANIZATIONAL ROLE DETERMINATION

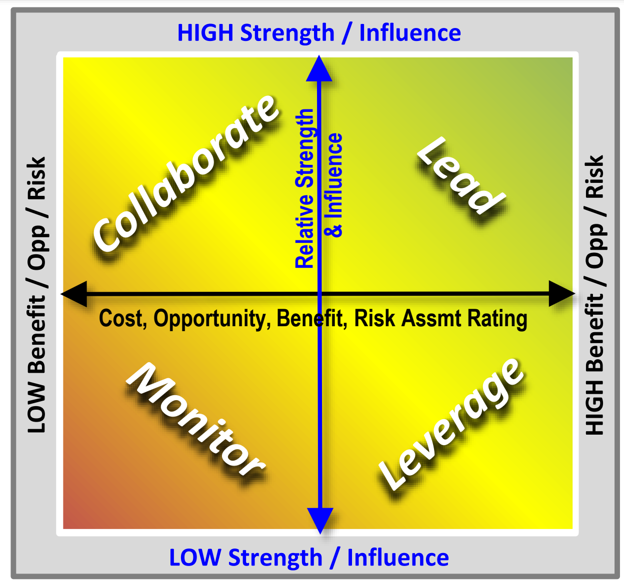
Determining what Role an Organization should Adopt

- **SWOT analysis** is an initialism for ***S**trengths, **W**eaknesses, **O**pportunities*, and ***T**hreats*. It is a common technique traditionally used by organizations to help them determine whether or not they should pursue a business venture.
  - The *Strengths / Weaknesses axis* pertains to the attributes of the **organization** (internal)
  - The *Opportunity / Threat axis* pertains to the attributes of the **environment** (external)



SWOT Analysis Matrix

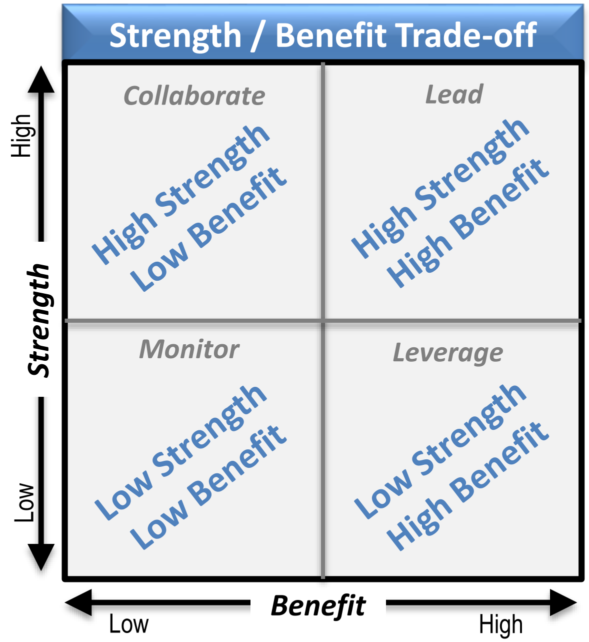
- A similar technique can be applied to assist organizations with determining the role they should take-on within the community.
  - The *Relative Strengths & Influence axis* pertains to the attributes of the **organization** (internal)
  - The *Cost, Opportunity, Benefit, Risk Assmt axis* pertains to the attributes of the **environment** (external)
- Organizations can determine whether they should ***Lead, Collaborate, Leverage*** or ***Monitor*** based on which quadrant the opportunity falls

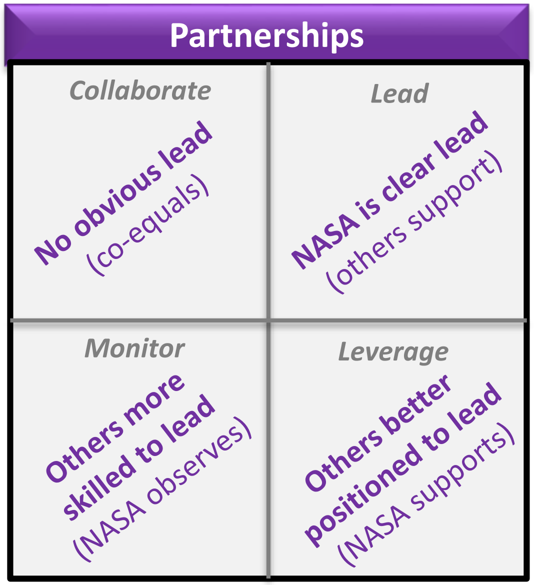


Lead / Collaborate / Leverage / Monitor Matrix

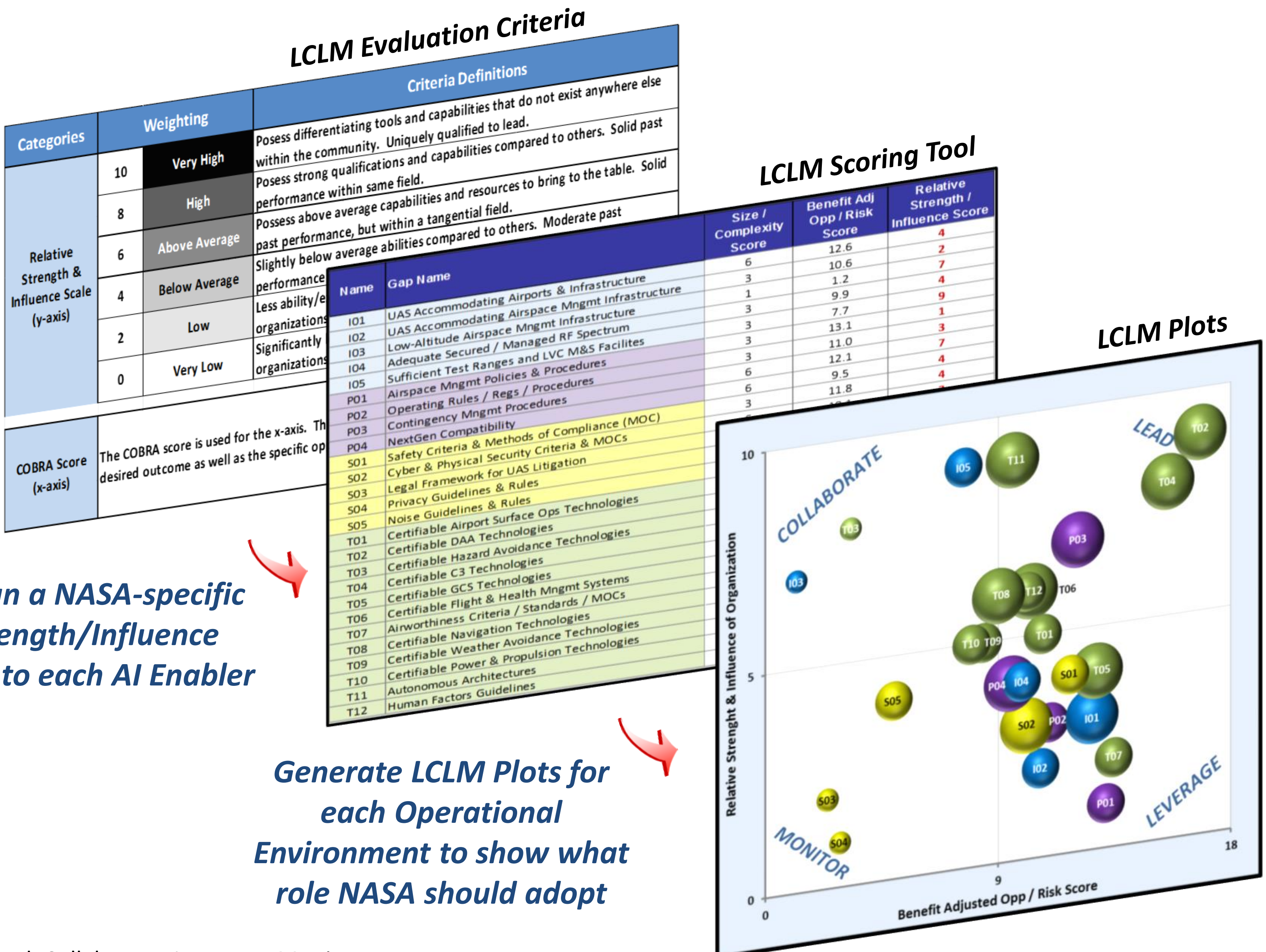
Organizational Role Implications

Organizational Designation		Organizational Role Implications Specific for NASA
Lead		NASA is obvious choice to take on leadership role based on their unique strengths and the potential benefit that will be achieved by addressing the challenge head-on. As lead, NASA will be required to invest more than others and take on most of risk.
Collaborate		No obvious lead exists. NASA should identify strategic partners who can help address meaningful parts of the challenge so together a better solution can be achieved in a more time-efficient and cost-effective way than by going alone. Moderate risks and costs will be required.
Leverage		NASA should support other organizations who are better positioned/equipped to lead the effort and/or leverage their work. Use what they have already accomplished to advance NASA's efforts. The other organization will be taking on a larger portion of the risks and associated costs.
Monitor		NASA should identify others in the community who are obvious leaders in the given field and observe what they are doing, without having an ability to impact the results. Learn from their research findings. No risks or resources are required.





Organizational Role Determination



Assign a NASA-specific Strength/Influence score to each AI Enabler

Generate LCLM Plots for each Operational Environment to show what role NASA should adopt

LCLM = Lead, Collaborate, Leverage, Monitor

Organizational Role Scoring Criteria

Relative Strength & Influence Scale (y-axis)

Weighting Criteria		Criteria Definitions
10	Very High	Possesses differentiating tools and capabilities that do not exist anywhere else within the community. Uniquely qualified to lead.
8	High	Possesses strong qualifications and capabilities compared to others. Solid past performance within same field.
6	Above Average	Possesses above average capabilities and resources to bring to the table. Solid past performance, but within a tangential field.
4	Below Average	Slightly below average abilities compared to others. Moderate past performance in tangential field.
2	Low	Less ability/experience than others within the community. Other organizations are better suited to take the lead.
0	Very Low	Significantly less ability/experience than others within the community. Other organizations must take the lead based on charter / mission statement.

COBRA Score (x-axis)

The COBRA Score from the previous analysis is used for the x-axis. This takes into consideration the overall benefit to achieving the desired outcome as well as the opportunities and risks associated with each AI Enabler.

NASA's Strength & Influence Rating

Airspace Integration Enablers			Strength & Influence Rating
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	5
	T02	Certifiable DAA Technologies	9
	T03	Certifiable Hazard Avoidance Technologies	8
	T04	Certifiable C3 Technologies	8
	T05	Certifiable GCS Technologies	4
	T06	Certifiable Flight & Health Mngmt Systems	6
	T07	Airworthiness Criteria / Standards / MOCs	2
	T08	Certifiable Navigation Technologies	6
	T09	Certifiable Weather Avoidance Technologies	5
	T10	Certifiable Power & Propulsion Technologies	5
	T11	Autonomous Architectures	9
	T12	Human Factors Guidelines	6
Policies, Procedures & NextGen	P01	Airspace Mngmt Policies & Procedures	1
	P02	Operating Rules / Regs / Procedures	3
	P03	Contingency Mngmt Procedures	7
	P04	NextGen Compatibility	4
Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	3
	I02	UAS Accommodating Airspace Mngmt Infrastructure	2
	I03	Low-Altitude Airspace Mngmt Infrastructure	9
	I04	Adequate Secured / Managed RF Spectrum	4
	I05	Sufficient Test Ranges and LVC M&S Facilites	9
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	5
	S02	Cyber & Physical Security Criteria & MOCs	4
	S03	Legal Framework for UAS Litigation	2
	S04	Privacy Guidelines & Rules	1
	S05	Noise Guidelines & Rules	6

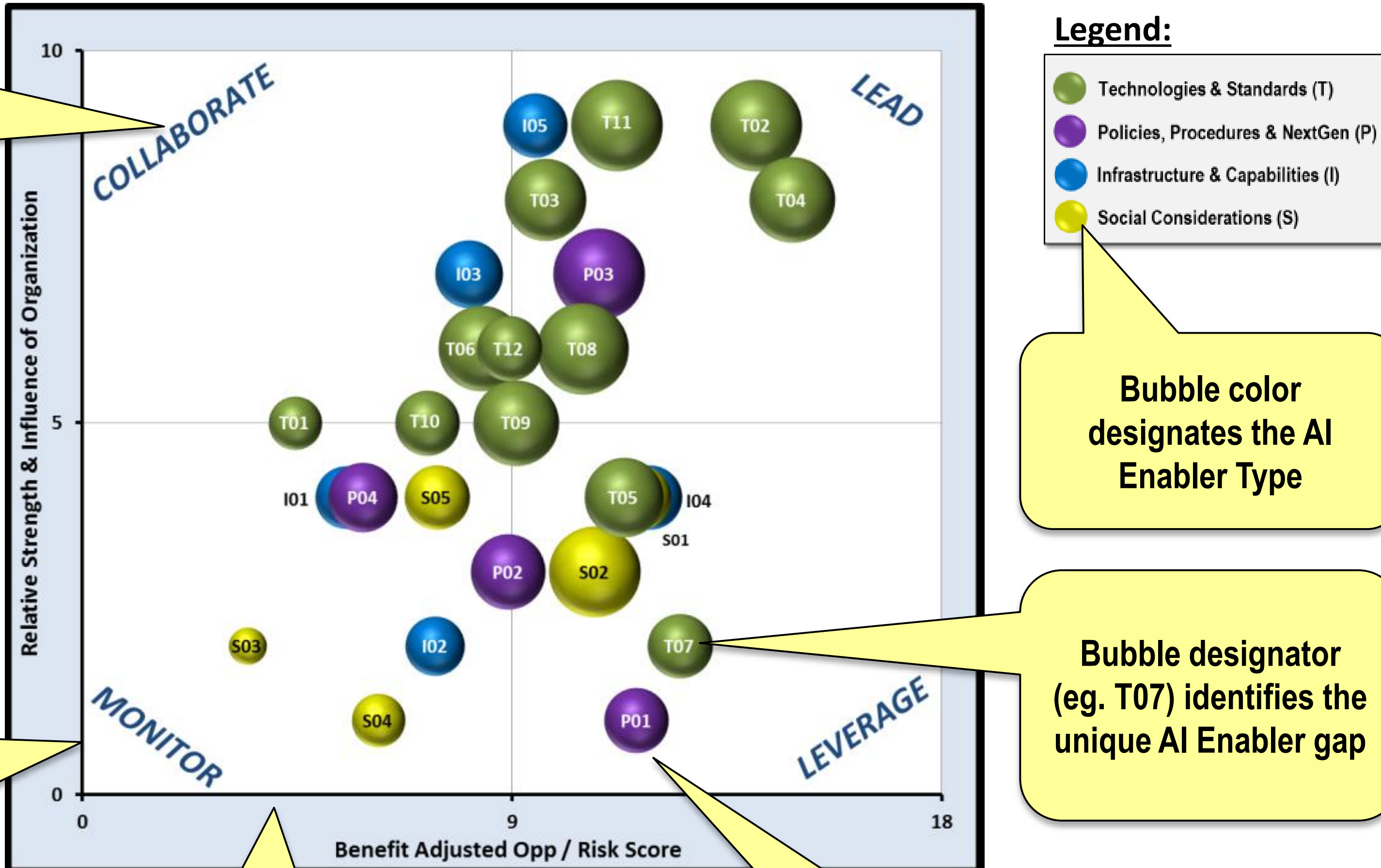
Strength & Influence Rating Scale:

Weighting Criteria	
10	Very High
8	High
6	Above Average
4	Below Average
2	Low
0	Very Low

The same NASA Strength & Influence ratings were used for each Operational Environment assessment

How to Read an LCLM Bubble Plot

Notional Plot



Quadrant title specifies the role NASA should likely adopt for all bubbles within that quadrant

Y-axis is NASA's Strength / Influence Score (0 – 10) relative to the AI Enabler gap

X-axis is the COBRA Score (0 – 18) resulting from the Tornado Plots

Bubble size is the relative investment cost score for the AI Enabler gap

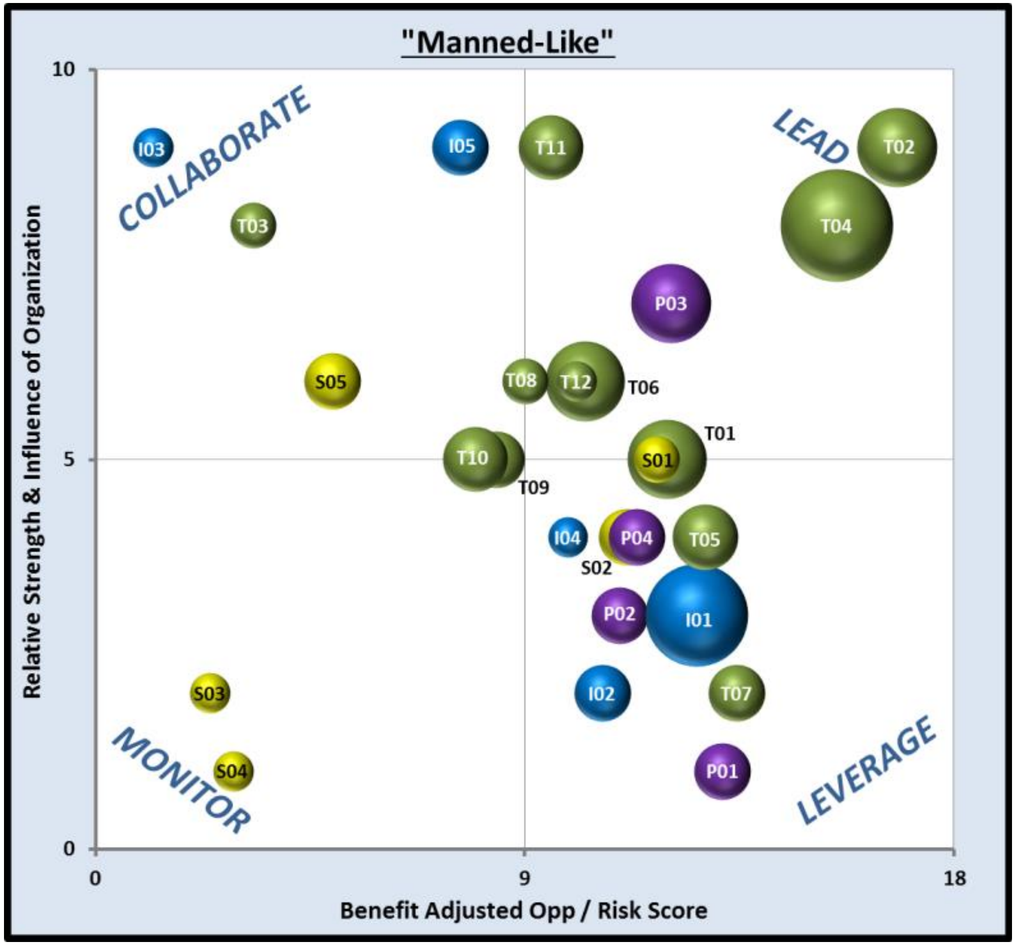
Bubble color designates the AI Enabler Type

Bubble designator (eg. T07) identifies the unique AI Enabler gap

LCLM Assessment Results

I. "Manned-like" IFR

LCLM	Gap Name
Lead	T01 - Airport Surface Ops
Lead	T02 - DAA Technologies
Collaborate	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Leverage	T05 - GCS Technologies
Lead	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Collaborate	T08 - Navigation
Collaborate	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Lead	T12 - Human Factors Guidelines
Leverage	P01 - Airspace Mngmt Pol. / Proc.
Leverage	P02 - Operating Rules / Regs
Lead	P03 - Contingency Mngmt
Leverage	P04 - NextGen Compatibility
Leverage	I01 - Airport Infrastructure
Leverage	I02 - Airspace Infrastructure
Collaborate	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Collaborate	I05 - Test Ranges and LVC
Lead	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Monitor	S04 - Privacy
Collaborate	S05 - Noise



Key Findings:

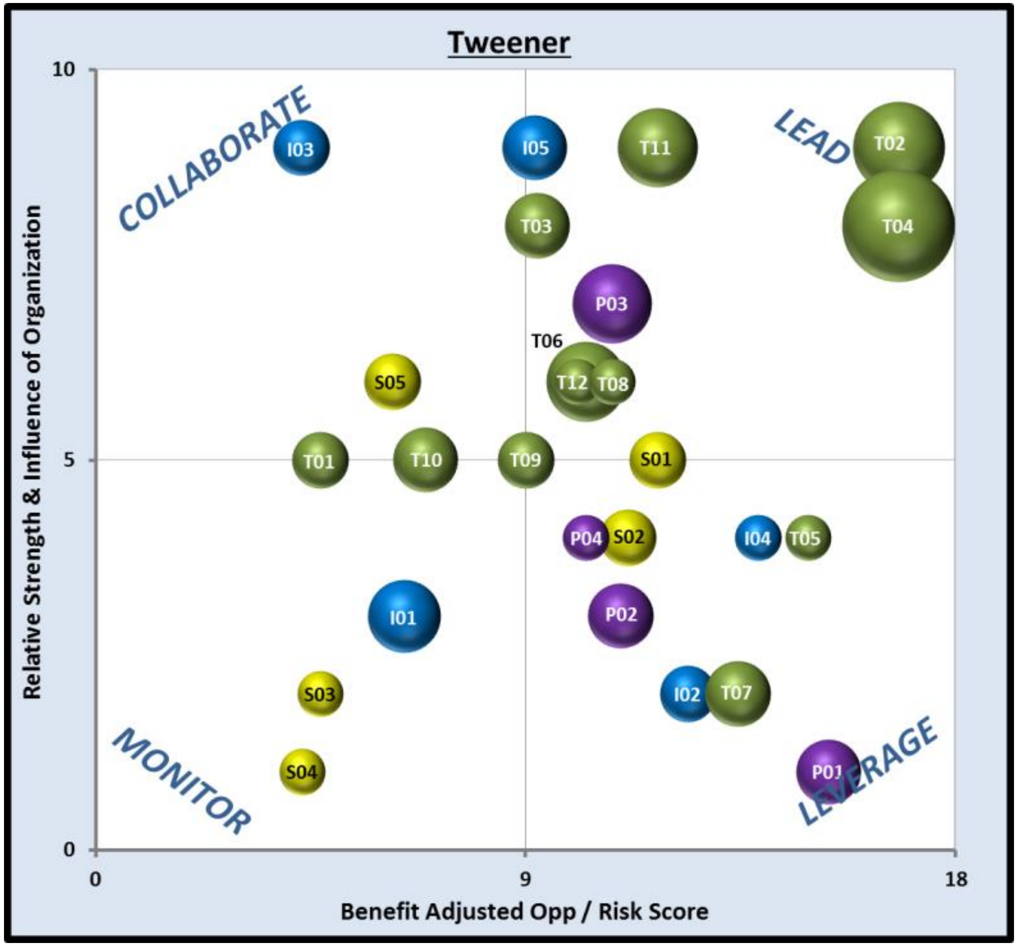
- The majority of the gaps are on the right side of plot because of their high importance to the community
- Several clear leads already exist across community since these gaps have been a focus for several years
- NASA should consider leading several Technology gaps (Surface Ops, DAA, C3, Flight Mngmt, Auton. Arch., HF)
- NASA should also consider leading Contingency Management (P03) and Safety (S01)

LCLM Assessment Results

II. Tweeners

- Technologies & Standards (T)
- Policies, Procedures & NextGen (P)
- Infrastructure & Capabilities (I)
- Social Considerations (S)

LCLM	Gap Name
Collaborate	T01 - Airport Surface Ops
Lead	T02 - DAA Technologies
Lead	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Leverage	T05 - GCS Technologies
Lead	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Lead	T08 - Navigation
Collaborate	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Lead	T12 - Human Factors Guidelines
Leverage	P01 - Airspace Mngmt Pol. / Proc.
Leverage	P02 - Operating Rules / Regs
Lead	P03 - Contingency Mngmt
Leverage	P04 - NextGen Compatibility
Monitor	I01 - Airport Infrastructure
Leverage	I02 - Airspace Infrastructure
Collaborate	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Lead	I05 - Test Ranges and LVC
Leverage	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Monitor	S04 - Privacy
Collaborate	S05 - Noise



Key Findings:

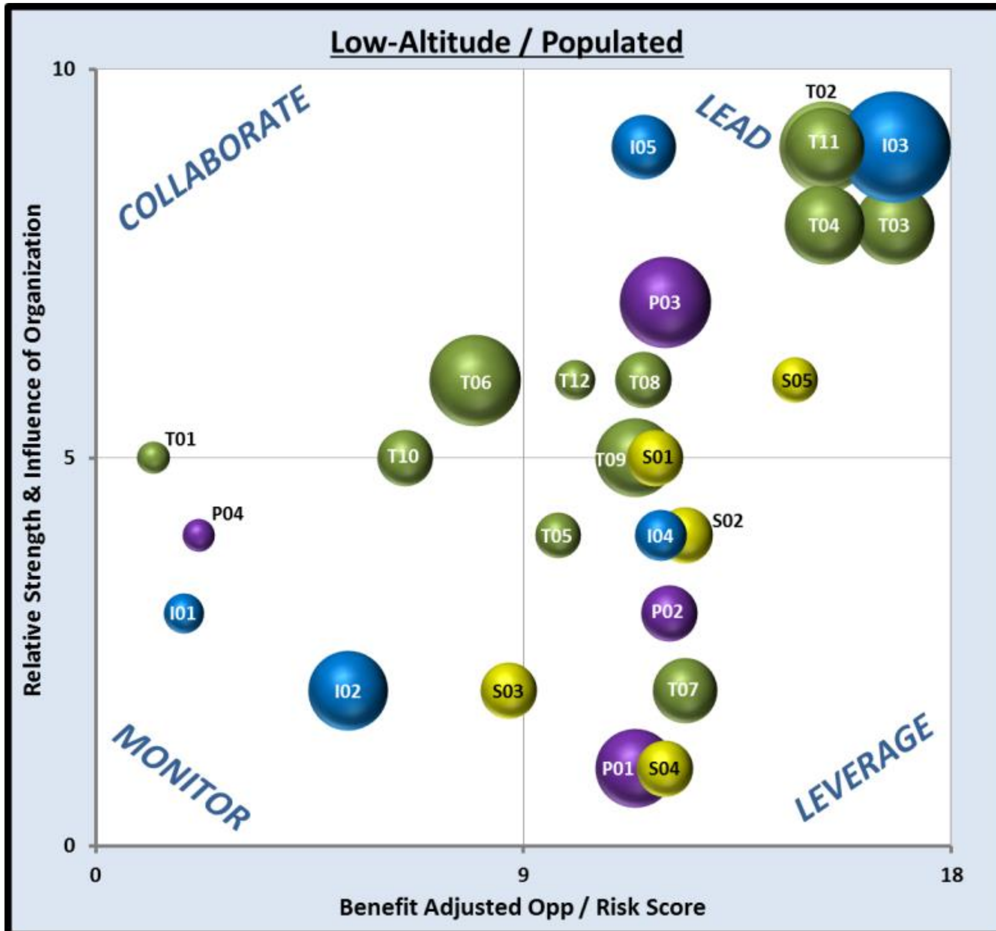
- The bubble size (representing relative cost) for several gaps increase compared to "Manned-like" because the challenges are more difficult and have not been the focus of recent initiatives
- Hazard Avoidance (T03) & Auton. Arch. (T11) are more important for the Tweener OEs than "Manned-like"
- Airport Surface Ops (T01) & Airport Infrastructure (I01) are less important / costly compared to "Manned-like"

LCLM Assessment Results

III. Low Altitude Populated

- Technologies & Standards (T)
- Policies, Procedures & NextGen (P)
- Infrastructure & Capabilities (I)
- Social Considerations (S)

LCLM	Gap Name
Collaborate	T01 - Airport Surface Ops
Lead	T02 - DAA Technologies
Lead	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Leverage	T05 - GCS Technologies
Collaborate	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Lead	T08 - Navigation
Leverage	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Lead	T12 - Human Factors Guidelines
Leverage	P01 - Airspace Mngmt Pol. / Proc.
Leverage	P02 - Operating Rules / Regs
Lead	P03 - Contingency Mngmt
Monitor	P04 - NextGen Compatibility
Monitor	I01 - Airport Infrastructure
Monitor	I02 - Airspace Infrastructure
Lead	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Lead	I05 - Test Ranges and LVC
Leverage	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Leverage	S04 - Privacy
Lead	S05 - Noise



Key findings:

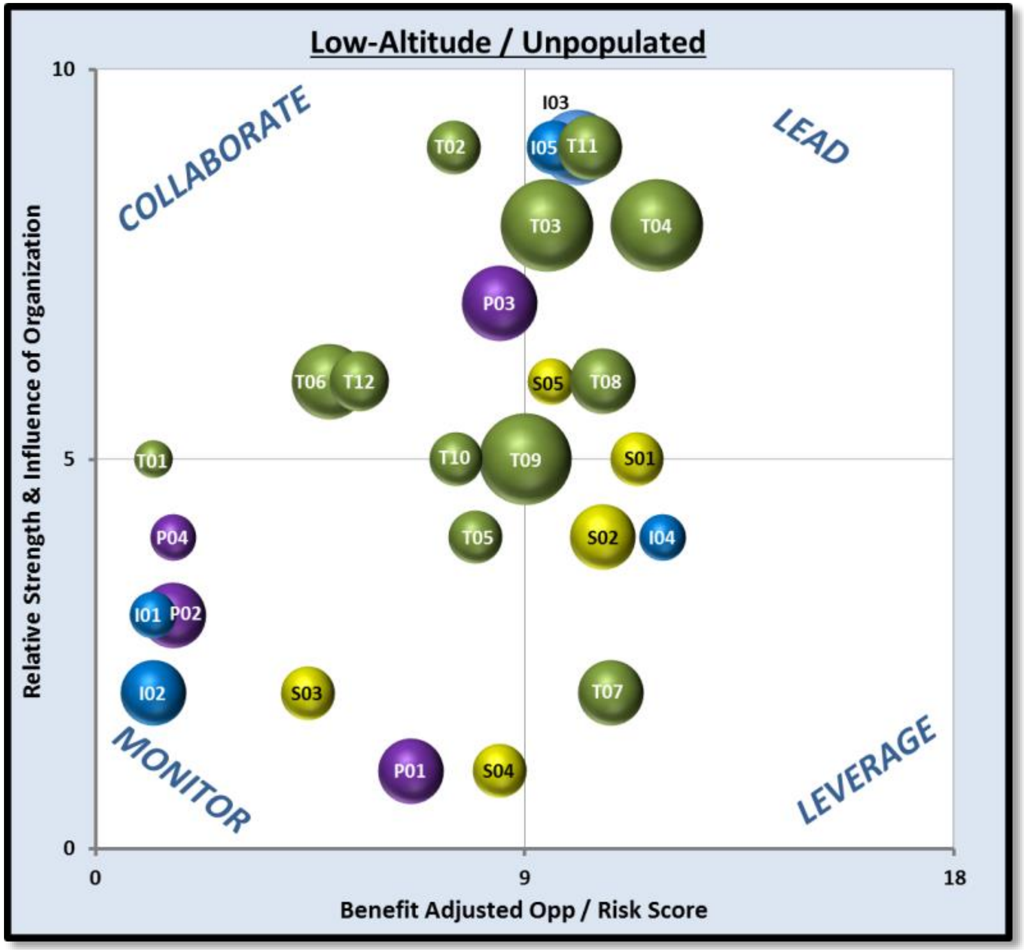
- The majority of the gaps are on the right side of plot because of their high importance to the community
- NASA should consider leading multiple Technology gaps (DAA, C3, Hazard Avoidance, Auton. Arch)
- I03: Low Altitude Traffic Management is the number one need for this OE
- Social Considerations are more important for the Low Altitude Oes than they are for “Manned-like” or Tweener

LCLM Assessment Results

IV. Low Altitude Unpopulated

Technologies & Standards (T)
Policies, Procedures & NextGen (P)
Infrastructure & Capabilities (I)
Social Considerations (S)

LCLM	Gap Name
Collaborate	T01 - Airport Surface Ops
Collaborate	T02 - DAA Technologies
Lead	T03 - Hazard Avoidance
Lead	T04 - C3 Technologies
Monitor	T05 - GCS Technologies
Collaborate	T06 - Flight & Health Mngmt
Leverage	T07 - Airworthiness
Lead	T08 - Navigation
Collaborate	T09 - Weather Avoidance
Collaborate	T10 - Power & Propulsion
Lead	T11 - Autonomous Architectures
Collaborate	T12 - Human Factors Guidelines
Monitor	P01 - Airspace Mngmt Pol. / Proc.
Monitor	P02 - Operating Rules / Regs
Collaborate	P03 - Contingency Mngmt
Monitor	P04 - NextGen Compatibility
Monitor	I01 - Airport Infrastructure
Monitor	I02 - Airspace Infrastructure
Lead	I03 - Low-Alt. Traffic Mngmt
Leverage	I04 - RF Spectrum
Lead	I05 - Test Ranges and LVC
Leverage	S01 - Safety Criteria & MOCs
Leverage	S02 - Cyber & Physical Security
Monitor	S03 - Legal
Monitor	S04 - Privacy
Lead	S05 - Noise

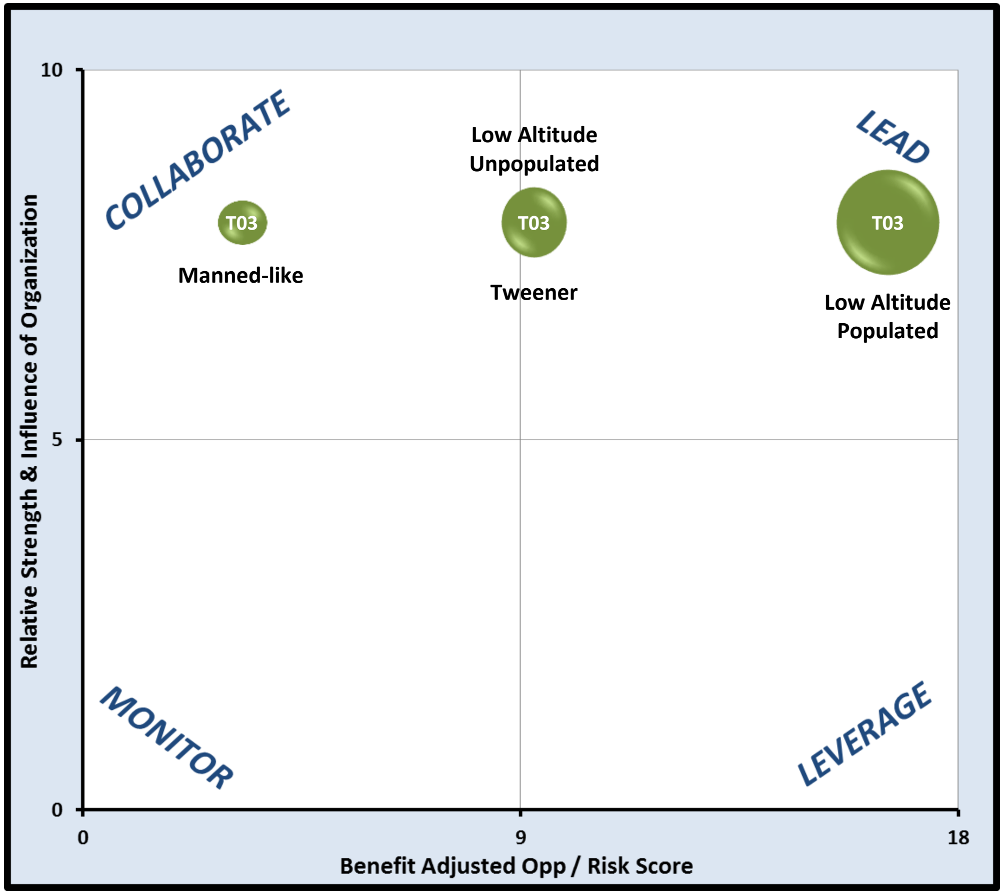


Key Findings:

- The majority of the gaps fall along the y-axis; indicating the community need is moderate and not as great as the other three OEs
- NASA should consider leading multiple Technology gaps (C3, Hazard Avoid., Auton. Arch, Navigation) as well as Low-Alt. Traffic Mngmt (I03), Test/LVC (I05) and Noise (S05)

How do the AI Enablers Migrate across Quadrants?

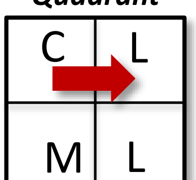
Technology & Standards Example



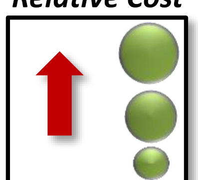
- **AI Enabler**: ***T03 – Hazard Avoidance***
- **Migration Path**:
  - Manned: **Collaborate**
  - Tweener: **Lead**
  - Low Alt. / Pop: **Lead**
  - Low Alt. / Unpop: **Lead**
- **Relative Cost:**
  - Manned: **Low**
  - Tweener: **Medium**
  - Low Alt. / Pop: **High**
  - Low Alt. / Unpop: **Medium**
- **Key Finding:**
  - Hazard Avoidance is not needed for the Manned-like OE, but becomes increasingly important for the Tweener and Low Alt. Populated OE's.
  - NASA has significant strength & influence regarding this AI Enabler and should consider leading any efforts to address this challenge.

Trends:

Quadrant

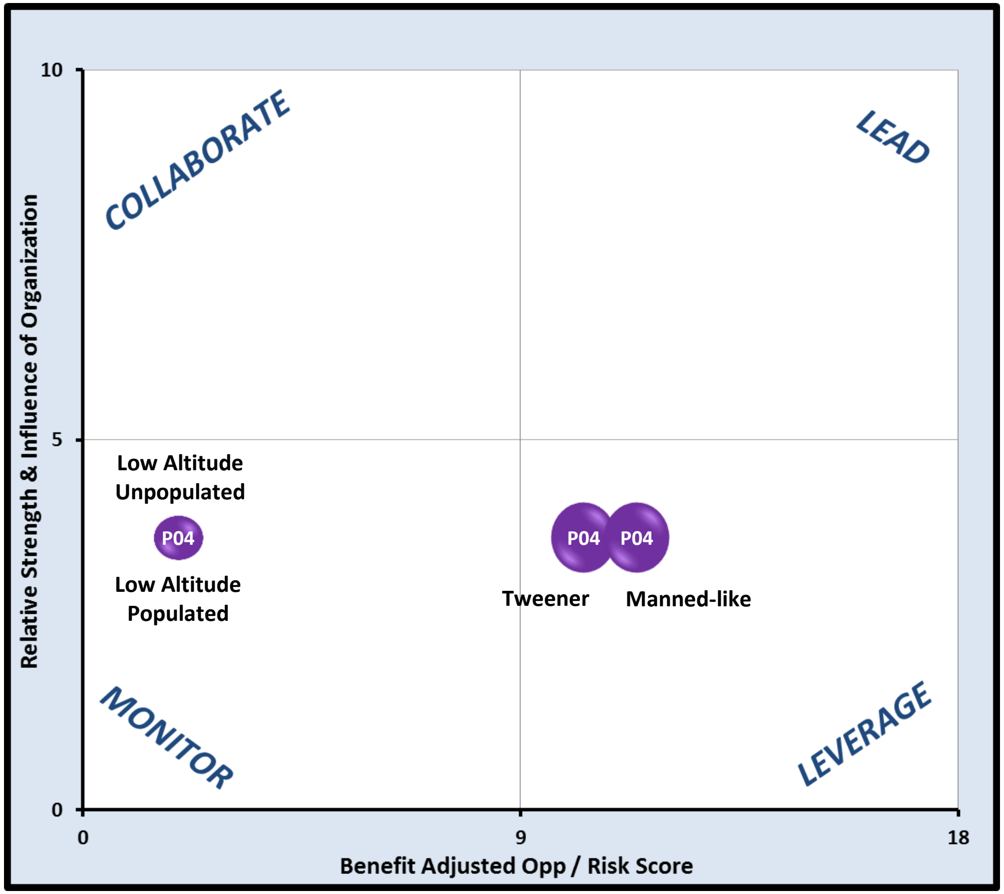


Relative Cost



How do the AI Enablers Migrate across Quadrants?

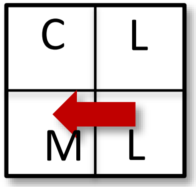
Policy, Procedures & NextGen Example



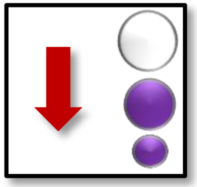
- **AI Enabler**: ***P04 – NextGen Compatibility***
- **Migration Path**:
  - Manned: **Leverage**
  - Tweener: **Leverage**
  - Low Alt. / Pop: **Monitor**
  - Low Alt. / Unpop: **Monitor**
- **Relative Cost:**
  - Manned: **Medium**
  - Tweener: **Medium**
  - Low Alt. / Pop: **Low**
  - Low Alt. / Unpop: **Low**
- **Key Finding:**
  - NextGen compatibility is essential for full integration within the Manned-like and Tweener OE's.
  - Current indications are that the planned NextGen technologies will not be available for use within the Low-Altitude OE's.

Trends:

Quadrant

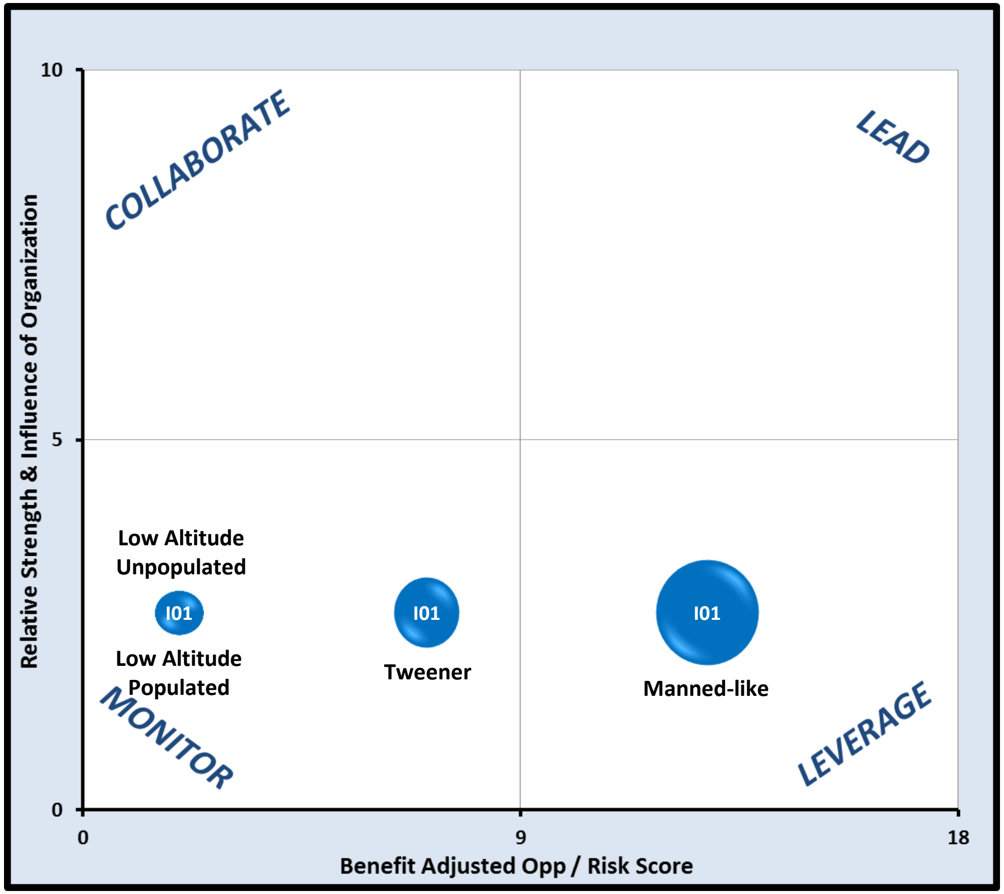


Relative Costs



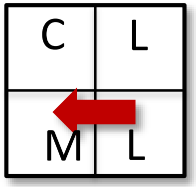
How do the AI Enablers Migrate across Quadrants?

Infrastructure & Capabilities Example

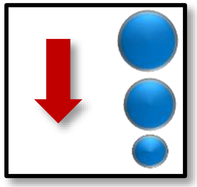


Trends:

Quadrant



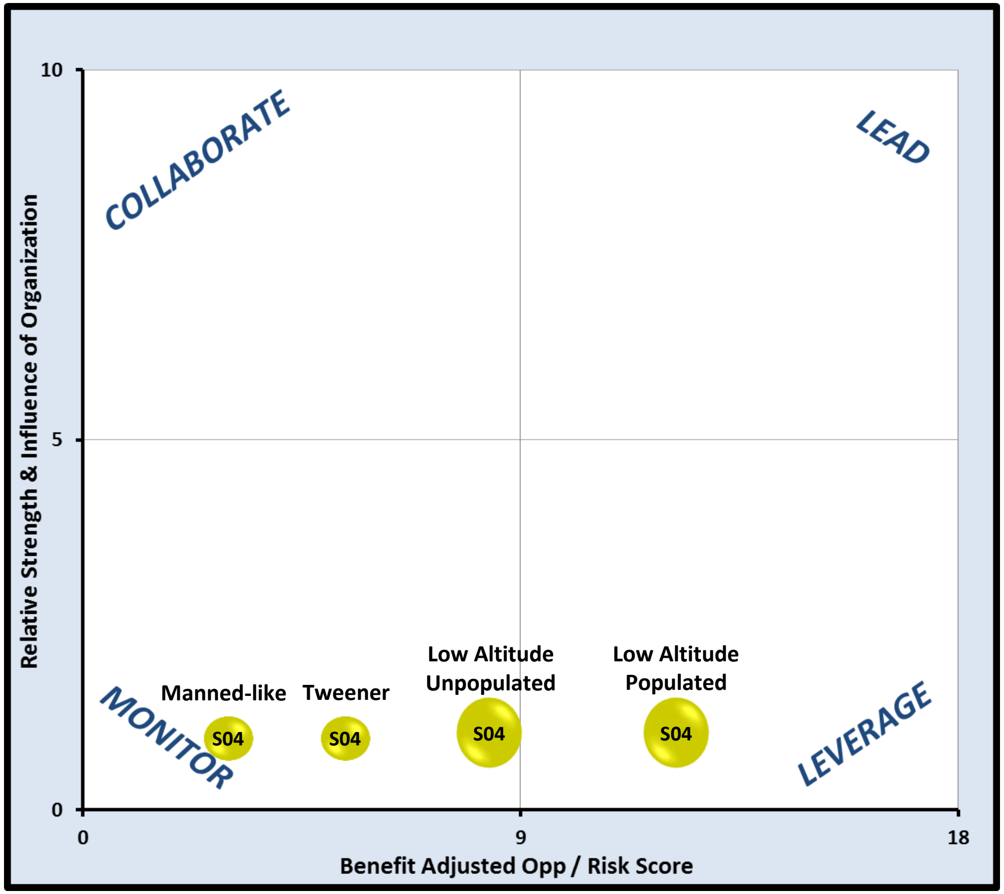
Relative Cost



- **AI Enabler**: ***I01 – UAS Accommodating Airports & Infrastructure***
- **Migration Path**:
  - Manned: **Leverage**
  - Tweener: **Monitor**
  - Low Alt. / Pop: **Monitor**
  - Low Alt. / Unpop: **Monitor**
- **Relative Cost :**
  - Manned: **High**
  - Tweener: **Medium**
  - Low Alt. / Pop: **Low**
  - Low Alt. / Unpop: **Low**
- **Key Finding:**
  - Accommodating airports and infrastructure is essential for the Manned-like OE, beneficial for the Tweener OE, but of little value to both Low Alt. OE's.
  - NASA has relatively low to moderate strength & influence regarding this AI Enabler and should consider allowing others to take the lead.

How do the AI Enablers Migrate across Quadrants?

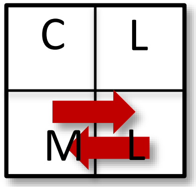
Social Considerations Example



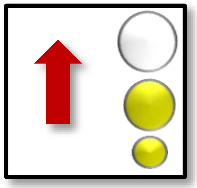
- **AI Enabler**: *S04 – Privacy Guidelines/Rules*
- **Migration Path**:
  - Manned: **Monitor**
  - Tweener: **Monitor**
  - Low Alt. / Pop: **Leverage**
  - Low Alt. / Unpop: **Monitor**
- **Relative Cost :**
  - Manned: **Low**
  - Tweener: **Low**
  - Low Alt. / Pop: **Medium**
  - Low Alt. / Unpop: **Medium**
- **Key Finding:**
  - Privacy Guidelines are of little importance for the Manned-like OE, is moderately important for the Tweener and Low Alt. Unpopulated OE's, but is very important for the Low-Alt. Populated OE.
  - NASA has relatively low strength & influence regarding this AI Enabler and should consider allowing others to take the lead.

Trends:

Quadrant

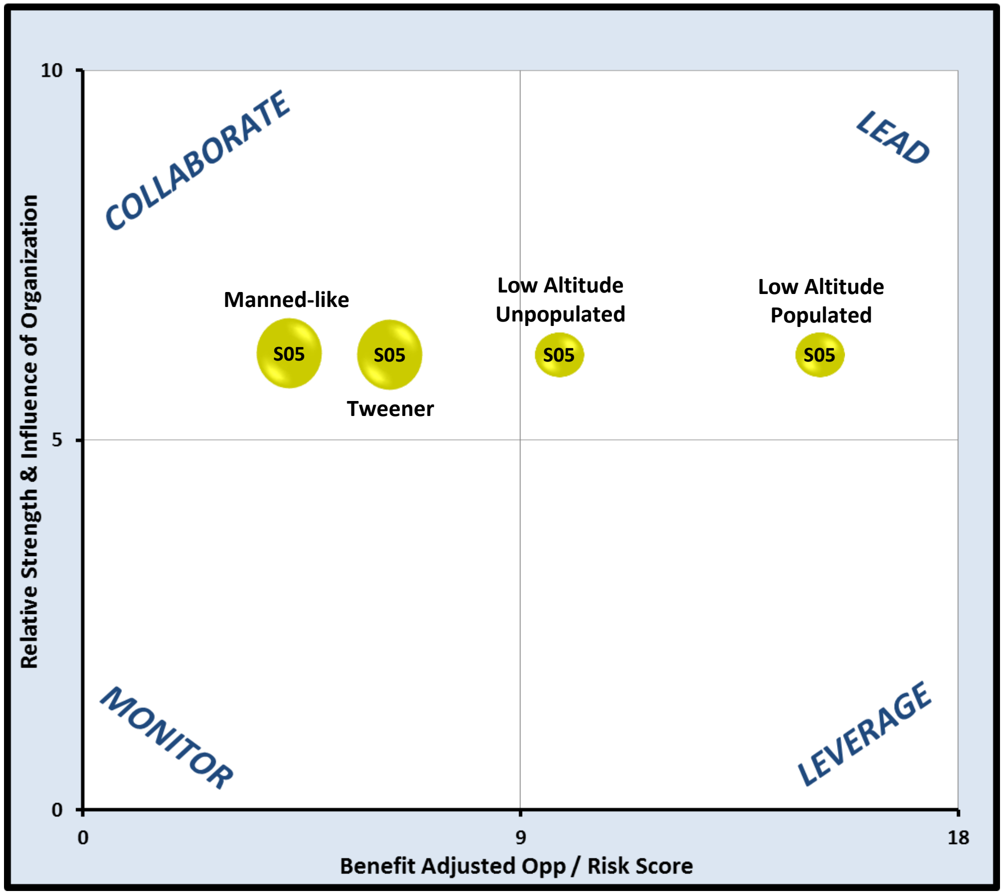


Relative Cost



How do the AI Enablers Migrate across Quadrants?

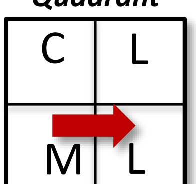
Social Considerations Example



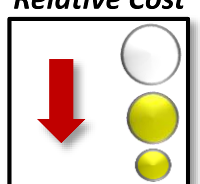
- **AI Enabler**: ***S05 – Noise Guidelines/Rules***
- **Migration Path**:
  - Manned: **Collaborate**
  - Tweener: **Collaborate**
  - Low Alt. / Pop: **Lead**
  - Low Alt. / Unpop: **Lead**
- **Relative Cost :**
  - Manned: **Medium**
  - Tweener: **Medium**
  - Low Alt. / Pop: **Low**
  - Low Alt. / Unpop: **Low**
- **Key Finding:**
  - Noise Guidelines are of little importance for the Manned-like OE, is moderately important for the Tweener and Low Alt. Unpopulated OE’s, but is very important for the Low-Alt. Populated OE.
  - NASA has above average strength and influence for this AI Enabler and should consider leading it for both Low-Altitude OEs.
  - Anticipate costs to solve and implement for Low Alt. OE will be less than Manned-like & Tweener OEs since the Low Alt. engines are less complex and many are electric motors, which already have a low noise signature.

Trends:

Quadrant



Relative Cost



NASAs Potential Role in UAS Full Integration

LCLM Roll-up

Airspace Integration Enablers			Operational Environment: Man-Like IFR (I)	Tweener (II)	Low-Alt / Popul. (III)	Low-Alt / Unpop. (IV)	LCLM Summary: Lead	Collab.	Leverage	Monitor
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	Lead	Collaborate	Collaborate	Collaborate	1	3	0	0
	T02	Certifiable DAA Technologies	Lead	Lead	Lead	Collaborate	3	1	0	0
	T03	Certifiable Hazard Avoidance Technologies	Collaborate	Lead	Lead	Lead	3	1	0	0
	T04	Certifiable C3 Technologies	Lead	Lead	Lead	Lead	4	0	0	0
	T05	Certifiable GCS Technologies	Leverage	Leverage	Leverage	Monitor	0	0	3	1
	T06	Certifiable Flight & Health Mngmt Systems	Lead	Lead	Collaborate	Collaborate	2	2	0	0
	T07	Airworthiness Criteria / Standards / MOCs	Leverage	Leverage	Leverage	Leverage	0	0	4	0
	T08	Certifiable Navigation Technologies	Collaborate	Lead	Lead	Lead	3	1	0	0
	T09	Certifiable Weather Avoidance Technologies	Collaborate	Collaborate	Lead	Collaborate	1	3	0	0
	T10	Certifiable Power & Propulsion Technologies	Collaborate	Collaborate	Collaborate	Collaborate	0	4	0	0
	T11	Autonomous Architectures	Lead	Lead	Lead	Lead	4	0	0	0
	T12	Human Factors Guidelines	Lead	Lead	Lead	Collaborate	3	1	0	0
Policies / Procedures NextGen	P01	Airspace Mngmt Policies & Procedures	Leverage	Leverage	Leverage	Monitor	0	0	3	1
	P02	Operating Rules / Regs / Procedures	Leverage	Leverage	Leverage	Monitor	0	0	3	1
	P03	Contingency Mngmt Procedures	Lead	Lead	Lead	Collaborate	3	1	0	0
	P04	NextGen Compatibility	Leverage	Leverage	Monitor	Monitor	0	0	2	2
Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	Leverage	Monitor	Monitor	Monitor	0	0	1	3
	I02	UAS Accomm. Airspace Mngmt Infrastructure	Leverage	Leverage	Monitor	Monitor	0	0	2	2
	I03	Low-Altitude Airspace Mngmt Infrastructure	Collaborate	Collaborate	Lead	Lead	2	2	0	0
	I04	Adequate Secured / Managed RF Spectrum	Leverage	Leverage	Leverage	Leverage	0	0	4	0
	I05	Sufficient Test Ranges and LVC M&S Facilites	Collaborate	Lead	Lead	Lead	3	1	0	0
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	Lead	Lead	Lead	Lead	4	0	0	0
	S02	Cyber & Physical Security Criteria & MOCs	Leverage	Leverage	Leverage	Leverage	0	0	4	0
	S03	Legal Framework for UAS Litigation	Monitor	Monitor	Monitor	Monitor	0	0	0	4
	S04	Privacy Guidelines & Rules	Monitor	Monitor	Leverage	Monitor	0	0	1	3
	S05	Noise Guidelines & Rules	Collaborate	Collaborate	Lead	Lead	2	2	0	0
							38	22	27	17

NASAs Potential Role in UAS Full Integration

Airspace Integration Enabler "Heat Map"

Airspace Integration Enablers			Man-Like IFR I	Tweener II	Low-Alt / Popul. III	Low-Alt / Unpop. IV	sum
Technology & Standards	T01	Certifiable Airport Surface Ops Technologies	60	24	6	6	95
Technology & Standards	T02	Certifiable DAA Technologies	151	151	138	68	508
Technology & Standards	T03	Certifiable Hazard Avoidance Technologies	26	74	134	76	310
Technology & Standards	T04	Certifiable C3 Technologies	124	134	123	94	475
Technology & Standards	T05	Certifiable GCS Technologies	51	60	39	32	181
Technology & Standards	T06	Certifiable Flight & Health Mngmt Systems	62	62	48	29	200
Technology & Standards	T07	Airworthiness Criteria / Standards / MOCs	27	27	25	22	100
Technology & Standards	T08	Certifiable Navigation Technologies	54	65	69	64	252
Technology & Standards	T09	Certifiable Weather Avoidance Technologies	42	45	57	45	189
Technology & Standards	T10	Certifiable Power & Propulsion Technologies	40	35	33	38	145
Technology & Standards	T11	Autonomous Architectures	86	106	138	93	423
Technology & Standards	T12	Human Factors Guidelines	60	60	60	33	215
Policies / Procedures NextGen	P01	Airspace Mngmt Policies & Procedures	13	15	11	7	46
Policies / Procedures NextGen	P02	Operating Rules / Regs / Procedures	33	33	36	5	107
Policies / Procedures NextGen	P03	Contingency Mngmt Procedures	84	76	84	59	303
Policies / Procedures NextGen	P04	NextGen Compatibility	45	41	9	6	102
Infrastructure & Capabilities	I01	UAS Accommodating Airports & Infrastructure	38	19	6	4	66
Infrastructure & Capabilities	I02	UAS Accomm. Airspace Mngmt Infrastructure	21	25	11	2	59
Infrastructure & Capabilities	I03	Low-Altitude Airspace Mngmt Infrastructure	11	39	151	91	291
Infrastructure & Capabilities	I04	Adequate Secured / Managed RF Spectrum	40	55	48	48	190
Infrastructure & Capabilities	I05	Sufficient Test Ranges and LVC M&S Facilities	69	83	104	86	342
Social Considerations	S01	Safety Criteria & Methods of Compliance (MOC)	59	59	59	57	233
Social Considerations	S02	Cyber & Physical Security Criteria & MOCs	45	45	50	42	181
Social Considerations	S03	Legal Framework for UAS Litigation	5	9	17	9	40
Social Considerations	S04	Privacy Guidelines & Rules	3	4	12	8	28
Social Considerations	S05	Noise Guidelines & Rules	30	37	88	57	212
		sum	1278	1382	1554	1080	
			2660		2634		
		sum "Top 10"	809	870	1,089	744	
			1,679		1,834		

(Column group header: Operational Environment)

T02 Certifiable DAA is the most important AI Enabler across all 4 OEs

Heat Map Legend

High NASA Strength x COBRA Score

Low NASA Strength x COBRA Score

NASA should consider leading the cells having the darkest color.

The Low Alt. Populated OE has the highest payoff given NASA's strength and influence

Note: Heat Map score = COBRA score multiplied by NASA's Strength/Influence score (i.e. X-axis x Y-axis)

NASAs Potential Role in UAS Full Integration

Cumulative "Heat Map"

Airspace Integration Enablers	Operational Environment				
	Man-Like IFR	Tweener	Low-Alt / Popul.	Low-Alt / Unpop.	
	I	II	III	IV	*sum*
Technology & Standards	65	70	72	50	**258**
Policies, Procedures & NextGen	44	41	35	19	139
Infrastructure & Capabilities	36	44	64	46	190
Social Considerations	28	31	45	35	139
sum	173	186	**216**	150	

The Technologies and Standards are the highest payoff for NASA

The Low Alt. Populated OE has the highest payoff for NASA's

Heat Map Legend

High NASA Strength x BaOR Score

Low NASA Strength x BaOR Score

Note: Cumulative Heat Map score = Average Heat map score for each AI Enabler Category

Key Findings:

- NASA's strongest contributions should be in the ***Technology & Standards*** and ***Infrastructure & Capabilities*** *gaps*
- Technology & Standards for ***Manned-Like***, ***Tweener*** & ***Low-Alt./Populated*** OE's are the 3 highest scoring categories
- The ***Low-Alt./Populated*** OE should be the highest pay-off area
- The ***Manned-Like and Tweener*** OE's are a close second and third pay-off area

High scoring gaps from the full UAS integration analysis are important for ARMD to consider research against. NASA should consider developing project goals or technical challenges around achieving DRM demonstration flights in final year of project

Leadership Considerations across all four Operational Environments

AI Enablers		Operational Environment: Man-Like IFR I	Tweener II	Low-Alt / Popul. III	Low-Alt / Unpop. IV	Sum	Overall Rank	# Times Placed into "Lead" Quadrant
T02	Certifiable DAA Technologies	151	151	138	68	508	1	3
T04	Certifiable C3 Technologies	124	134	123	94	475	2	4
T11	Autonomous Architectures	86	106	138	93	423	3	4
I05	Sufficient Test Ranges and LVC M&S Facilites	69	83	104	86	342	4	3
T03	Certifiable Hazard Avoidance Technologies	26	74	134	76	310	5	3
P03	Contingency Mngmt Procedures	84	76	84	59	303	6	3
I03	Low-Altitude Airspace Mngmt Infrastructure	11	39	151	91	291	7	2
T08	Certifiable Navigation Technologies	54	65	69	64	252	8	3
S01	Safety Criteria & Methods of Compliance (MOC)	59	59	59	57	233	9	4
T12	Human Factors Guidelines	60	60	60	33	215	10	3
S05	Noise Guidelines & Rules	30	37	88	57	212	11	2
T06	Certifiable Flight & Health Mngmt Systems	62	62	48	29	200	12	2
I04	Adequate Secured / Managed RF Spectrum	40	55	48	48	190	13	0
T09	Certifiable Weather Avoidance Technologies	42	45	57	45	189	14	1
T05	Certifiable GCS Technologies	51	60	39	32	181	15	0
S02	Cyber & Physical Security Criteria & MOCs	45	45	50	42	181	16	0
T10	Certifiable Power & Propulsion Technologies	40	35	33	38	145	17	0
P02	Operating Rules / Regs / Procedures	33	33	36	5	107	18	0
P04	NextGen Compatibility	45	41	9	6	102	19	0
T07	Airworthiness Criteria / Standards / MOCs	27	27	25	22	100	20	0
T01	Certifiable Airport Surface Ops Technologies	60	24	6	6	95	21	1
I01	UAS Accommodating Airports & Infrastructure	38	19	6	4	66	22	0
I02	UAS Accomm. Airspace Mngmt Infrastructure	21	25	11	2	59	23	0
P01	Airspace Mngmt Policies & Procedures	13	15	11	7	46	24	0
S03	Legal Framework for UAS Litigation	5	9	17	9	40	25	0
S04	Privacy Guidelines & Rules	3	4	12	8	28	26	0

Key Findings:

- Overall Heatmap scores correlate closely to the number of times an AI Enabler was placed into the "Lead" quadrant
- NASA should consider leading the "Top 12"prioritized AI Enablers:
  1) DAA Technologies
  2) C3 Technologies
  3) Autonomous Architectures
  4) Test Ranges & LVC M&S
  5) Hazard Avoidance
  6) Contingency Management
  7) Low Alt. Airspace Mngmt
  8) Navigation Technologies
  9) Safety Criteria & MOCs
  10) Human Factors Guidelines
  11) Noise Guidelines
  12) Certifiable Flight & Health Mngmt

Questions?

BACK-UP

Identify Community Needs/Gaps/Challenges

- Leverage previous UAS Full Integration Studies performed in 2014 & 2015
  - Assessed 27 documents from multiple organizations identifying several hundred community needs/gaps
- Also need to consider new efforts & recent developments
  - NASA UTM
  - FAA Guidance (e.g. sUAS Rule)
  - Industry business cases
- Should engage UAS community stakeholders (as required) to ensure nothing is missing
  - OGA's (e.g. FAA, DoD, DHS, NOAA)
  - Trade Associations (e.g. AUVSI, AIAA)
  - Industry (e.g. Amazon, Google)
  - Academia (e.g. COE, UND)
  - International (e.g. ICAO, NATO)
- Utilize community needs/gaps to determine the Airspace Integration Enablers
  - Input to Decision Support Tool
  - Basis for Analytical Framework

	UAS Community Documents Used to Derive Needs / Gaps / Challenges
1	ASTM F.38 Standards Gap Analysis Briefing
2	JPDO NextGen UAS Research, Development and Demonstration Roadmap
3	GAO Report: Measuring Progress and Addressing Potential Privacy Concerns Would Facilitate Integration Into the NAS.
4	FAA Integration of UAS into the NAS Concept of Operations, Version 2.0
5	FAA Integration of Civil UAS into the NAS Roadmap
6	FAA SAA Second Workshop Final Report
7	NASA UAS-NAS Project Recommendations (Objectives + Technical Proposals)
8	GAO Report: Continued Coordination, Operational Data, and Performance Standards Needed to Guide Research and Development
9	UAS ARC Integration of Civil UAS in the NAS Implementation Plan
10	JPDO NextGen UAS R&D Prioritization Briefing
11	Terms of Reference, RTCA SC-228 Minimum Performance Standards for UAS
12	European RPAS Roadmap for the integration of civil Remotely-Piloted Aircraft Systems
13	JPDO UAS Comprehensive Plan
14	DoD Report to Congress on UAS Challenges
15	Inter-Center Autonomy Study Team (ICAST) Briefing
16	CANSO ANSP Considerations for RPAS Operations
17	IG Audit of FAA Oversight of UAS
18	NRC Study: Autonomy Research for Civil Aviation: Toward a New Era of Flight
19	NextGen SPC Actions: Initial FY14 Results
20	UAS ExCom Science and Research Panel Gap list
21	DoD Report to Congress on UAS R&D
22	GAO Report on UAS Integration
23	FAA Small UAS Notice of Public Rulemaking (NPRM)
24	GAO Report on Test Sites and International Cooperation
25	EASA RPAS CONOPS
26	USGS UAS Roadmap 2014
27	UTM CONOPS

Documents reviewed for previous study effort identified 350+ community needs

UAS Full Integration

What Being Finished Looks Like

Focus Area Bin	What Being Finished Looks Like
Airport Surface Ops	Airport surface operational requirements and standards have been adopted and the supporting technologies, both on-board and off-board, are developed and certified for use on all airport-capable UAS and at UAS accommodating airports.
Airspace Management	Adoption of all airspace procedures for UAS Operations within all classes of airspace. Development and acceptance of systems that enable aircraft to autonomously share and assess information to make decisions that improve system performance objectives such as capacity, safety, and efficiency.
Automation	Design, development and validation of autonomous architectures & technologies for multi-vehicle ops, self deterministic flight path planning, sensing, perception & cognition.
Certification Criteria	Adoption of all Airworthiness Criteria, Standards and Methods of Compliance (MOCs) for large and small UAS with varying levels of autonomy.
Contingency Management	Published guidelines & standards for contingency planning and handling of in-flight contingencies for all levels of autonomy in all classes of airspace. Certified technologies that enable self awareness, health monitoring & correction.
Detect and Avoid	Published requirements and standards for Detect and Avoid (i.e. aircraft, obstacles, ground) within all classes of airspace. Certified technologies for safely detecting, alerting, avoiding hazards and interoperating with ATM.
Human Systems Integration	Human factor guidelines and standards defined for man-in-the-loop, man-on-the-loop and fully autonomous UAS. UAS/Pilot and UAS/ATM requirements defined. GCS technologies developed and certified for all levels of autonomy.
Navigation	Published navigation standards for UAS operations within all classes of airspace. Certified navigation technologies, to include ground navigation and flight path planning. Certified GPS anti-jamming/anti-spoofing technologies.
Operating Rules/Regs (Large UAS)	Adoption of all Requirements / Rules / Regs for Large UAS operations within all classes of airspace. Published FAA Orders, Advisory Circulars (AC), AIM, Pilot/Crew Quals, Training & Medical requirements for large UAS.
Operating Rules/Regs (Small UAS)	Adoption of all Requirements / Rules / Regs for Small UAS operations within applicable classes of airspace. Published FAA Orders, ACs, AIM, Pilot/Crew Qualifications, Training & Medical requirements. Published VLOS & BVLOS Rules.
Power & Propulsion	Adoption of Power / Propulsion requirements and standards. Development and certification of power and propulsion technologies that increase safety, improve vehicle reliability, and increase endurance.
Reliable & Secure C3	Published C2-link, ATC-Comm link and link security standards for UAS operations within all classes of airspace. Certified C3 technologies. All RF Spectrum required for UAS airspace integ. secured through FCC and WRC.
Safety Criteria	Published Safety requirements and standards for all types of UAS operations in all classes or airspace. Defined acceptable level of safety. Guidelines established for allocation, substantiation, tracking and reporting of UAS safety.
Social Concerns	Proven guidelines and techniques for addressing UAS social concerns such as legal, privacy, noise, emissions, safety, and trust with adaptive / non-deterministic systems. Demonstrated international leadership in UAS adoption.
Test & Evaluation	Establishment of a relevant test environment for assessing UAS technologies and procedures. Fully operational FAA UAS Test Sites. Multiple civil/commercial airports capable of accommodating all types of UAS.
Weather	Certified technologies for weather event detection and avoidance or mitigation during UAS operations, to include unique turbulence events such as wake vortices, or icing conditions.